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DEVELOPMENT OF IMPROVED PYROELECTRIC DETECTORS

Literature survey of pyroelectric materials and their characteristics

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16. Abstract

The object of this program is to improve the detectivity of the pyroelectric detector with the ultimate goal of operation at or near the temperature-noise limit. Two general areas of investigation are undertaken. The first is to improve responsivity through the use of new materials. The second is directed toward reduction of noise and will be effected with improved field effect transistor characteristics, and improved electroding of the pyroelectric material.

The search for new materials has begun with a review of the literature on pyroelectric materials in several languages. The compiled data includes an extensive list of references. From this, several materials have already been selected for investigation.

FET's are being obtained from various manufacturers, evaluated, and selected units will be tested with pyroelectric elements as complete detectors.

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PREFACE

The object of this program is to improve the detectivity of the pyroelectric detector with the ultimate goal of operation at or near the temperature-noise limit. Two general areas of investigation are undertaken. The first is to improve responsivity through the use of new materials, the use of thinner sections of material, and through the application of the dielectric mode. The second is toward reduction of noise through improved field effect transistor characteristics and improved electroding of the pyroelectric material.

The search for new materials has begun with a review of the literature on pyroelectric materials. This will continue for the duration of the program. The literature search will result in a compilation of potentially useful materials and their available characteristics. An extensive list of references is included.

As the data is collected, it is reviewed and materials are selected for investigation. Materials will be purchased if available. Crystals that are not available but can be grown from saturated aqueous solutions, will be grown at Barnes Engineering. Materials of interest will be examined and their pertinent characteristics measured. The more promising materials will be processed into detectors so that the detector characteristics may be measured and evaluated. Part of the detector construction effort will be devoted to the development of techniques for obtaining thin sections of pyroelectric material, and for the investigation of electroding techniques.

Field Effect Transistors (FET's) will be obtained from various manufacturers and evaluated for those characteristics affecting detector performance. FET's exhibiting improved characteristics will be tested with pyroelectric elements as complete detectors.

During the period of this report, the bulk of the literature search was completed and several materials selected for further study. Some specialized

test equipment has been designed and construction started.

Project accomplishments to date are consistant with the objectives of the program.

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Section 1.0 INTRODUCTION

The first phase of this program has been carried out over a three month period beginning August 20, 1971 and ending November 22, 1971. The goals for this phase are listed:

1. Complete the major portion of the literature search. The literature search will be continued for the duration of the program.
2. Complete the major portion of a compilation of all materials potentially suitable for detectors and their available characteristics as derived from the liaterature search.
3. Purchase or begin the crystal growing of those materials that are immediately recognized as being of interest.
4. Define the measurements and test equipment required for the program. Design special equipment, purchase components, and begin construction.
5. Begin measurement of characteristics as material and equipment becomes available.

These goals were achieved, and each is discussed in turn in the remainder of this report.

Section 2.0 LITERATURE SEARCH

The available literature was culled for materials potentially useful in the infrared. The selection of papers was limited to those written in or translated into English, French, or German that discuss materials or techniques suitable for application in infrared pyroelectric detectors. Useful operating temperatures were limited to the approximate range of 195°K to 400°K. The literature search resulted in a compilation of potentially useful materials and their available characteristics. For each material, the following data was collected:

1. Pyroelectric Coefficient.
2. Curie Temperature.
3. Dielectric Constant and measurement frequency.
4. Loss Tangent and measurement frequency.
5. Thermal Capacitance.
6. A-C Resistivity (derived from loss tangent).
7. Figures of Merit (Sensitivity and Detectivity).

The compilation of materials and characteristics has resulted in the table in Appendix A of this report. The extensive list of references is noteworthy. The table will be expanded as additional information is obtained from current liaterature.

Section 3.0 SELECTION OF MATERIALS FOR INVESTIGATION

On the basis of all available data (see Appendix A) regarding the respective Figures of Merit for Responsivity and Detectivity the following materials (in two groups) have been selected for complete testing:

Group 1 (materials on hand or on order):

TGS

DTGS

TGFB

$Li_2SO_4 \cdot H_2O$

TGS/Se (15% Se)

$TGS_{0.88} \cdot TGFB_{0.12}$

$Sr_{0.75}\ Ba_{0.25}\ Nb_2\ O_6$

$LiTaO_3$

Polyvinylidene Fluoride

Group 2 (materials still to be grown or irradiated):

TGS with subsequent X-, γ-, and UV-irradiation

TGS/Se ($\sim$15% Se plus additives, possible Cu^{+2} or Cr^{+3})

TGS/Se ($\sim$5% Se)

DTGSe

$NaNO_2$

3.1 REASON FOR MATERIAL CHOICE

TGS - most available data to date.

DTGS and TGFB - higher Curie temperature than TGS, permitting higher ambient temperatures.

$Li_2SO_4 \cdot H_2O$ - has rather flat responsivity over a wide temperature range; also, can withstand higher relative humidity than TGS.

TGS/Se (either 5% or 15% Se, with or without additional doping) - these currently are reported to give the best detector performance.

TGS-TGFB - Since TGS and TGFB are completely miscible in all proportions, a crystal was grown from an equimolar solution of TGS and

TGFB. In agreement with Brezina et al. (B6) a crystal with $TGS_{0.88}$ -$TGFB_{0.12}$ ratio was obtained. Since this crystal is available and has a higher Curie temperature than TGS, it was also included.

SBN - This material has been cited repeatedly in the recent literature as a promising pyroelectric detector material. A barium content of 25% appears as the optimum composition.

$LiTaO_3$ - The very high Curie temperature permits this material to be used at very high ambient temperatures or energy levels.

Polyvinylidene Fluoride - Even though the expected detectivity of this material is an order of magnitude lower than TGS, it is included for further examination since it permits very economical construction of large area detectors or arrays.

TGS with X-ray, Gamma ray, or U-V-Irradiation of biased TGS causes locked-in polarization which inhibits depoling.

DTGSe - Ordinary TGSe would be an excellent pyroelectric detector material if it were not for its low Curie temperature (22.2°C). Deuteration raises the Curie temperature to a possible acceptable level (34.5°C).

$NaNO_2$ - was included because of its high Curie temperature and apparently low loss tangent.

3.2 REASON FOR MATERIAL OMISSION

Colemanite - has been omitted even though its parameters look extremely promising because the naturally occurring material has varying impurities (depending upon its source) which do not permit duplication of results. Moreover, it is difficult to obtain good crystal samples.* The synthetic Colemanite can only be grown as microcrystals which appear unsuitable for the current investigation.

GUL - has been omitted temporarily until more information regarding its growth or source of procurement becomes available.

*according to Dr. H. H. Wider of Naval Electronics Lab., San Diego, Calif.

Section 4.0 MEASUREMENTS

Measurements have been divided into three general categories. These are: measurement of material characteristics, measurement of FET characteristics, and measurement of detector characteristics.

4.1 MATERIAL CHARACTERISTICS

The literature search has disclosed wide variations in some of the material characteristics as reported by different investigators. The test conditions are sometimes unknown. At times the reported test conditions vary widely from the detector test conditions, which makes the usefulness of the material characteristics questionable.

All materials of interest that can be obtained by growth or through purchase will be tested to determine their characteristics on a wider and more thorough basis than has been previously reported. The measurements to be made are listed and the techniques and associated equipment are discussed below. Section 4.1.4 describes the material preparation prior to these tests.

4.1.1 Dielectric Constant and Loss Tangent

These will be measured as functions of frequency, bias (unless permanently polarized), and temperature. Frequencies will range from 20 Hz to 10 KHz. The specific frequencies are 20, 100, 1K and 10KHz. Temperatures will range from approximately -30° C to 5° C higher than the Curie temperature with a maximum temperature of 100° C. Bias voltages will be 0.01, 1, 10 and 50 volts. Capacitance and loss tangent will be measured on a General Radio Bridge, Type 1620 equipped with a variable bias supply. The dielectric constant will be derived from the capacitance and the pyroelectric specimen dimensions. A thermoelectrically cooled or heated sink will be used to set the temperature of the specimen.

4.1.2 Pyroelectric Coefficient

The pyroelectric coefficient will be measured by recording the change of electrical charge exhibited by a pyroelectric specimen with the corresponding change in temperature, using an X-Y recorder. The slope of the

recorded curve indicates the pyroelectric coefficient at the corresponding temperature. The same thermoelectric cooler-heater mentioned in 4.1.1 will be used to set the specimen temperature.

The electrical circuits used in the measurement of pyroelectric coefficient are shown in Figures 4-1 and 4-2. Temperature is displayed on the X-axis of the recorder. An iron-constantan thermocouple with an electrical reference junction is connected to a chopper-stabilized amplifier. The output is further amplified, inverted, and then applied to the recorder.

The charge produced by the pyroelectric material as it is subjected to a temperature change is recorded on the Y-axis of the recorder. The electrodes of the sample are connected to a charge-integrating amplifier located close to the sample holder. The signal passes through a second amplifier and then to the recorder. Since the integrating amplifier cannot integrate indefinitely, a shorting switch has been provided to discharge the amplifier. This will be done manually at approximately 3 to 4 minute intervals. At a later date, an automatic discharge system will be considered. The measured charge accumulated during a given temperature interval provides information for the calculation of the pyroelectric coefficient.

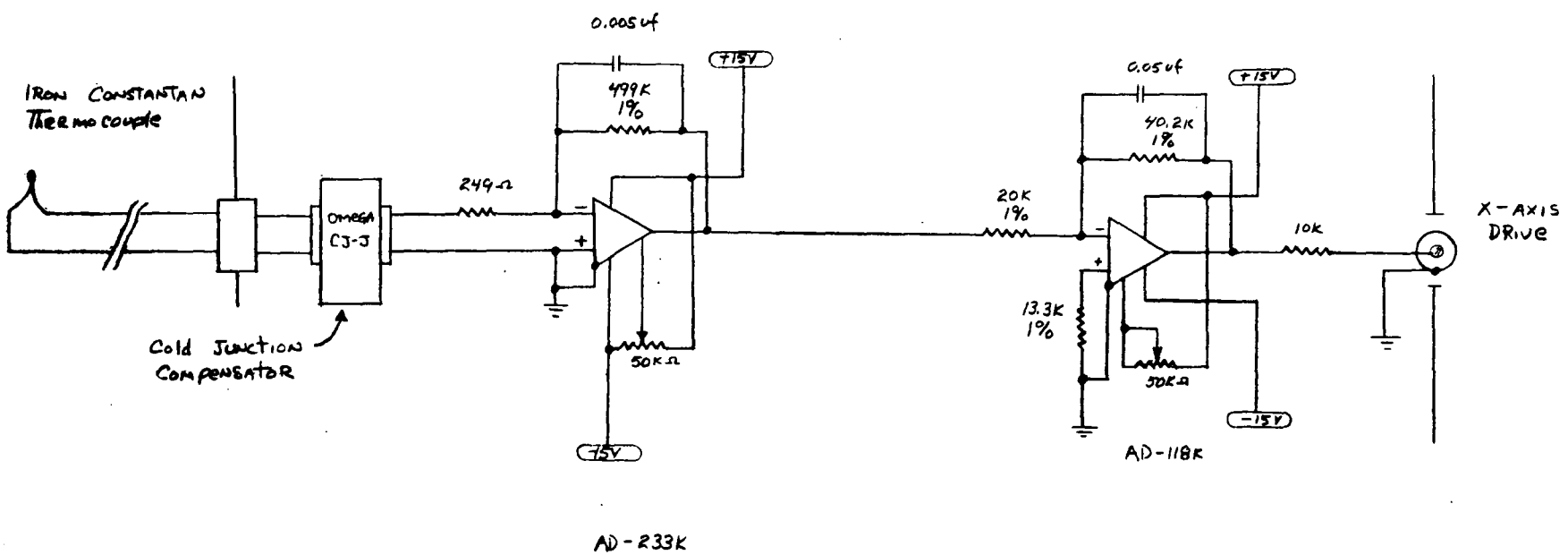
4.1.3 Transmittance and Reflectance

The Beckman DK-2 Spectrophotometer is used to measure transmittance and total reflectance from 0.3 to 3μ. Specular reflectance and transmittance in the range of 2 to 40μ is measured with a Beckman IR-20 Spectrophotometer. Measurements are made with no electrodes and again with a transparent nichrome electrode on one side of the sample.

The data obtained from these measurements is reported in Appendix B.

4.1.4 Sample Preparation

Material for the various measurements is prepared as shown in Table 4-1. The samples are mounted and housed in a container consisting of a four-pin metal header and a copper cover, Figure 4-3. The pyroelectric material sample is mounted directly to the metal header so that its temperature may be controlled and measured. Wire leads from the sample connect to the



4-1 THERMOCOUPLE AMPLIFIER CIRCUIT FOR PYROELECTRIC COEFFICIENT MEASUREMENT

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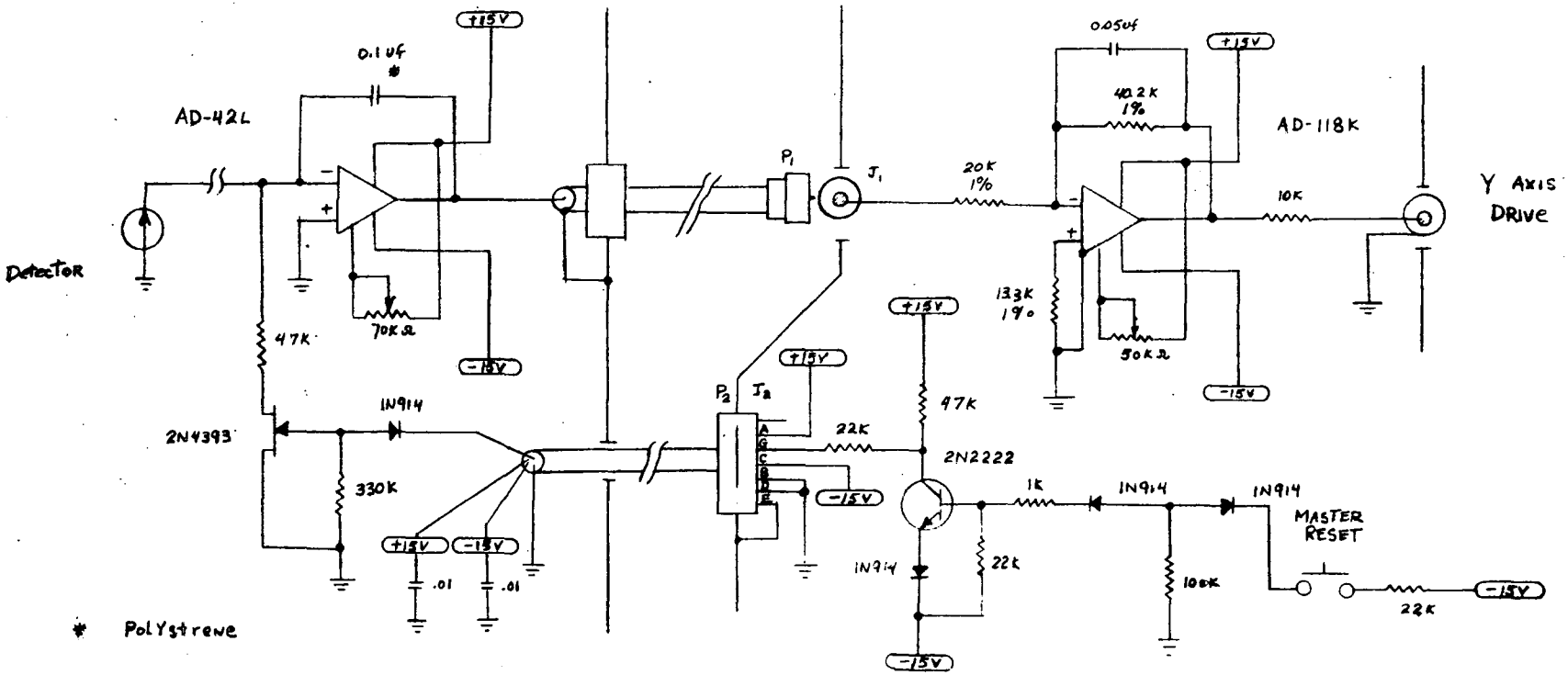

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4-2 CHARGE AMPLIFIER CIRCUIT FOR PYROELECTRIC COEFFICIENT MEASUREMENT

feed-through pins. The cover is cemented to the header with epoxy resin. No window is required for the dielectric constant, loss tangent, and pyroelectric coefficient measurements. The mounting for the responsivity measurements contains a KRS-5 window.

After the sample is mounted in the holder, the holder is attached to the thermal sink and coupled to the preamplifier as shown in Figure 4-4. All samples thus share the same environment and the same electrical signal processing.

4.2 FET Characteristics

There is some evidence that pyroelectric detector sensitivity is limited principally by noise associated with the FET impedance converters. Measurements will be made to select the best possible FET's for use in this application. The following characteristics are to be measured on a resonable sampling of candidate FET's purchased for the program:

1. Gate Leakage Current
2. Current Noise vs. Frequency and Temperature
3. Short Circuit Noise
4. Transconductance
5. Input Capacitance

4.2.1 Leakage Current

To achieve low noise in a pyroelectric detector system a principal requirement is to start with an FET that has low gate leakage current (I_{GSS}) and hence low current noise. At the same time this permits use of a large-value load resistor which, at high frequencies, leads to low Johnson noise. Direct measurement of low leakage currents of the order ot 1 pA is complicated when one is dealing with components operated in an open (humid) environment. A small chamber has been made up to free the input components (FET and gate load resistor) from humidity effects by vacuum pumping. The output characteristics can then be measured to indicate the leakage current.

TABLE 4-1 MATERIALS PREPARATIONS FOR CHARACTERISTIC MEASUREMENTS

Process	1	2	2A	3	4
Measurement	Transmittance, Reflectance 0.3 to 40μ	Transmittance, 0.3 to 40μ	Transmittance, 0.3 to 40μ	Dielectric Constant, Loss Tangent, Pyroelectric Coefficient	Responsivity, Noise
Material Preparation	Cleave, slice and lap to approx. 1 mm thick	Lap half the material in column 1 to approx. 0.1 mm thick	From Column 2	Cut 5 x 5 mm section from remaining material in column 1	Lap remaining material in column 2A to 0.04 mm. Preserve transparent coating.
Size	As lapped	As lapped	As lapped	5 x 5 x 1 mm	1.5 x 1.5 x 0.04 mm
Coating	None	None	One side Transparent Nichrome - 300 ohms per sq.	Side 1 - transparent Nichrome Side 2 - Opaque Nichrome	Side 1 - transparent Nichrome Side 2 - Opaque Nichrome
Mounting	None	None	None	4 pin base and copper cover	4 pin base, copper cover with KRS-5 window

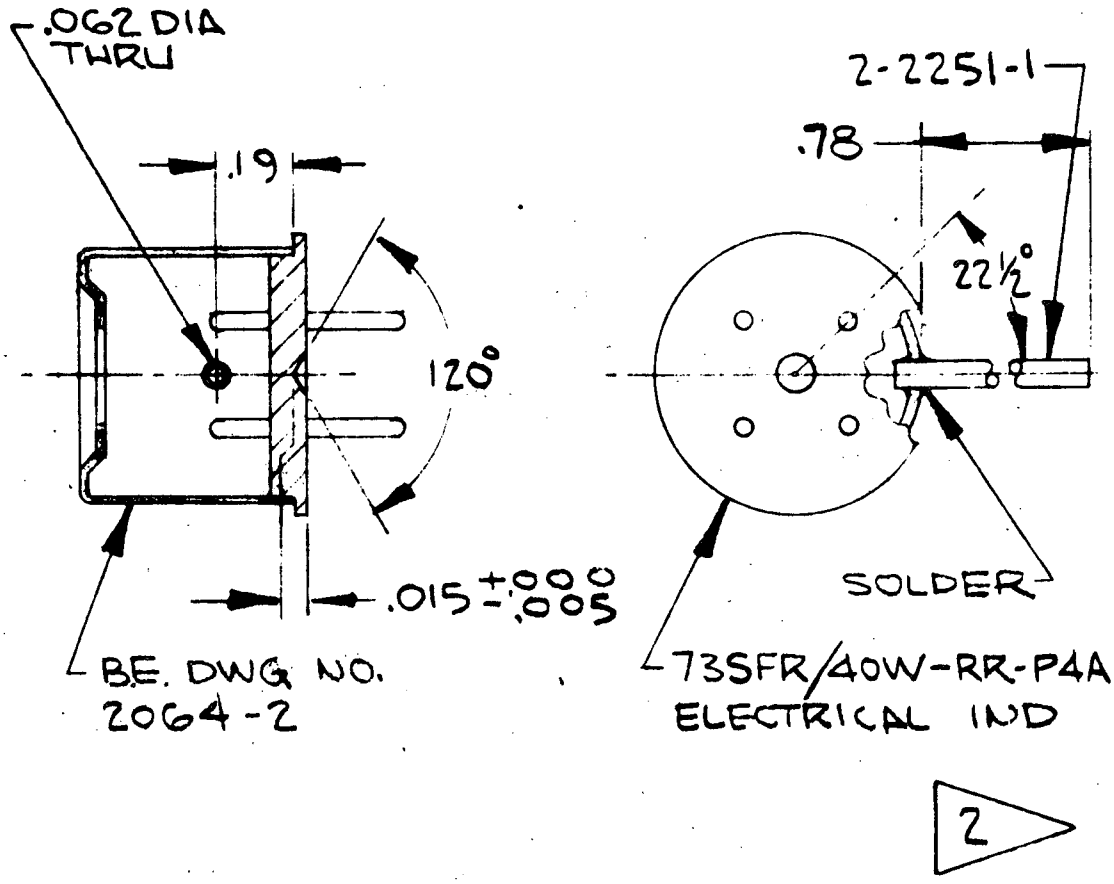

Figure 4-3 PYROELECTRIC SAMPLE HOLDER CONSTRUCTION DETAIL

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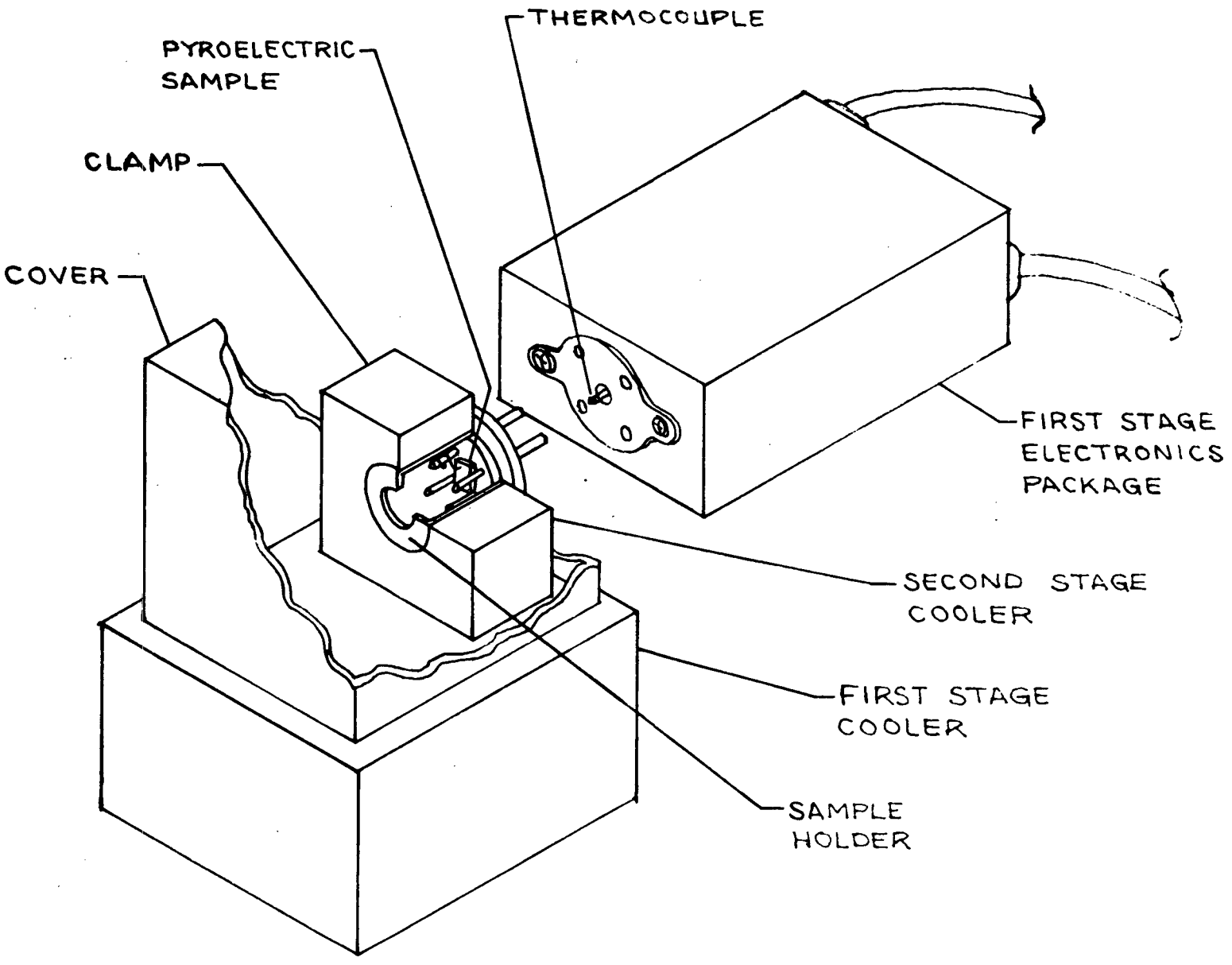


Figure 4-4 SAMPLE TEST SETUP

4.2.2 Leakage Current Noise

Leakage current induced noise is difficult to identify as such in the conventional mode of operation. The contribution to the measured output noise by the Johnson noise of the gate input resistor (R_L) and the possible detector loss resistance may be indistinguishable from noise due to the gate current. This condition can be modified by making measurements using several values of load resistance and replacing the detector element with known, low loss resistance capacitors. Figure 4-5 shows some typical noise curves. When using high values of load resistance (e.g. $R_L = 10^{12}$) the system is expected to be current-noise limited at all frequencies. For relatively low values of load resistance ($R_L < 10^{10}$) it may be Johnson noise limited (the noise being attributable to R_L). The readings obtained should permit positive identification and measurements of the noise constituents, both current and Johnson noise sources. These measurements are first made at room temperature. It is important that the amplifier following the FET be a low-noise device that will not degrade the measured response.

The measurements are also repeated at temperatures other than 20°C. These measurements will also provide clues to the character of the noise. A temperature increase by 20°C should increase the leakage current by 4 times and is expected to double the current noise.

4.2.3 Short-Circuit Noise

Noise measurements at high frequencies will indicate the short circuit noise of the FET's tested.

To extend the short circuit noise measurement to lower frequencies we plan to bypass the FET gate input resistor with a large value capacitor, and make noise measurements with a wave analyzer over a wide range of frequencies.

4.2.4 Transconductance

To be useful the FET's to be tested must have a minimal G_m of 500. Whether used in a common source or common drain configuration, the FET must provide gain in terms of voltage amplification or impedance conversion.

Johnson Noise, $V_{nJ} = \left[\frac{4 K T R_L}{1 + \omega^2 \tau_e^2}\right]^{1/2}$ Shot Noise, $V_{nSh} = \left[\frac{2 q I_{GSS} R_L^2}{1 + \omega^2 \tau_e^2}\right]^{1/2}$

Assume: $I_{GSS} = 1$ pA $C_D = 4$ pf

$\therefore I_{Sh} = \sqrt{2 q I_o \Delta f} = 6 \times 10^{-16}$ A Hz$^{-1/2}$ $\tau_e = R_L C_D$

$f_e = \frac{1}{2 \pi \tau_e} = \frac{1}{2 \pi R_L C_D}$

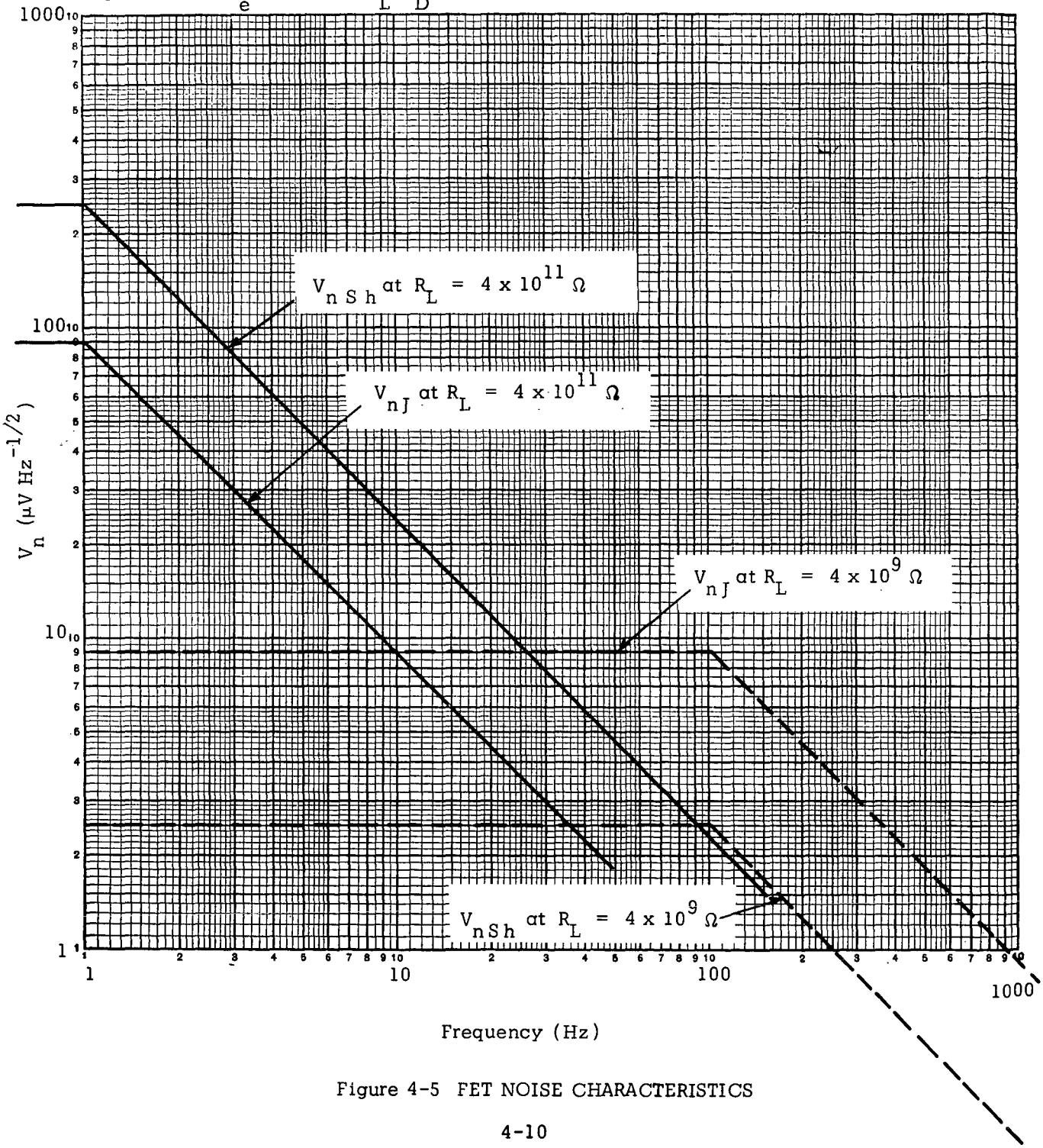


Figure 4-5 FET NOISE CHARACTERISTICS

In the common drain configuration normally used in this application, the transconductance can be determined simply from a measurement of the output impedance of the FET (in this case, source follower output impedance). This is done by feeding a small signal into the gate and measuring the source follower output voltage with varying load impedances applied until the output voltage drops to a measurably attenuated value (e.g. 1/2).

4.2.5 Input Capacitance

The detector input capacitance, which is essentially a shunt impedance to the detector capacitance and represents a loss in signal transferred into the amplifier, can be readily measured by determining the frequency response or high frequency cut-off point when feeding signals into the gate through a fixed and known source resistance.

If we apply to the FET gate a signal from an oscillator in series with a resistor (R_s) of $10^7\Omega$, and the FET output drops by 3 D B at a cutoff frequency (f_{hf}) 10 KHz, then the FET gate input capacitance, C_{iss}, is 1.6 pf, i.e.

$$C_{iss} = \frac{1}{2\pi R_s f_{hf}}$$

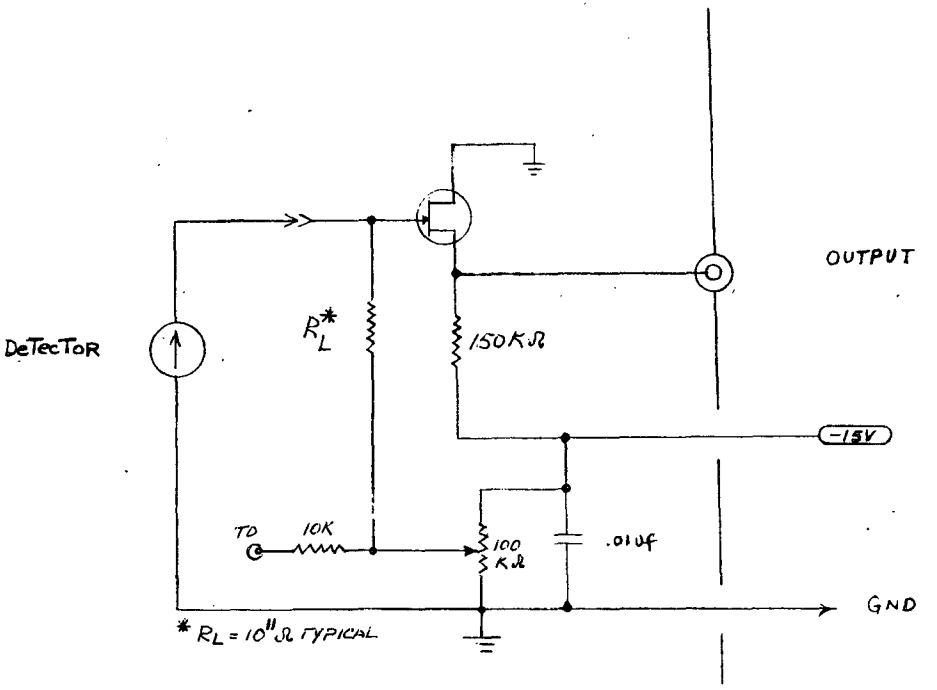
The test equipment for the tests discussed above is at hand. Three samples each of three types of FET have been obtained. Orders are now being placed for several others which have characteristics that appear to be promising. Measurements will be started in the next several weeks.

4.3 MEASUREMENT OF DETECTOR CHARACTERISTICS

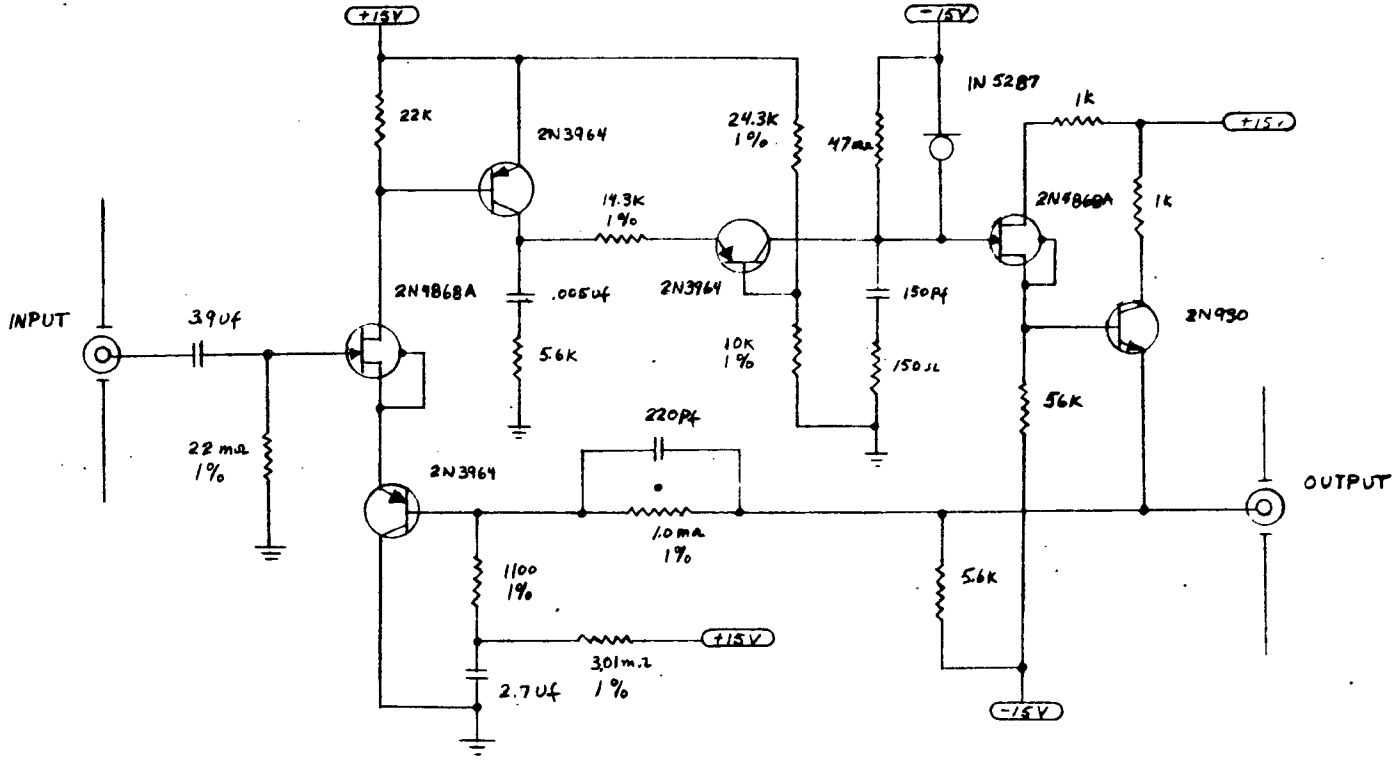
Materials are measured for responsivity and noise using the same thermoelectrically heated or cooled sink as in 4.1.1. The electronics for this test are shown schematically in Figures 4-6 and 4-7. The electronics are located outside of the pyroelectric sample container. This permits the same electronics to be used with all samples. The FET source follower is located close to the sample holder and its output is coupled by cable to the input of a low noise amplifier. The output of the amplifier will be read on a Hewlett-Packard Wave Analyzer in RMS volts. A blackbody and variable

speed chopper are used to irradiate the sample.

The same system is used to measure noise except that no radiant energy is required. Noise is measured in a 7 Hz bandwidth and is calculated for a 1 Hz bandwidth.



4-6 SOURCE-FOLLOWER CIRCUIT FOR DETECTOR RESPONSIVITY AND NOISE MEASUREMENT



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4-7 PREAMPLIFIER CIRCUIT FOR RESPONSIVITY AND NOISE MEASUREMENT

Section 5.0 NEW TECHNOLOGY

During this report period there were no technical developments reportable under the New Technology Clause of the subject contract.

Section 6.0 PLANNED FOR THE NEXT REPORTING PERIOD

The search for more pyroelectric materials (whose parameters might lead to satisfactory I-R detector operation) will continue, and the table of material parameters will be continuously updated with the most valid data.

Transmitance and reflectance measurements will continue on 1 mm as well as 0.1 mm thick samples.

On completion of the test equipment, the dielectric constant and loss tangent as functions of frequency and temperature will be determined for all available materials. The anticipated measurements will range in temperature from -30°C to 100°C at respectively 20, 100, 1K, and 10K Hz. The effect of bias on the dielectric constant and loss tangent will be investigated. The pyroelectric coefficient will also be measured over the indicated temperature range. If time permits during the next reporting period, detector elements 1.5mm x 1.5 mm x 0.04mm will be processed from the most promising detector materials. Subsequently, responsivity, noise, detectivity, and spectral response measurements will be made on these evacuated flakes as functions of temperature and frequency. The search for improved transistors and detector operation will continue simultaneously.

The effect of gamma and U-V-irradiation on TGS and DTGS will be investigated as well as the effects of Cu^{++} and Cr^{+++} doping. Either of these techniques should lead to "locked-in" polarization of single domains. This causes a shift in the hysteresis curve and implies that a detector will not have to be repoled after exceeding the FET temperature.

Measurements of sample FET's will begin.

Section 7.0 CONCLUSIONS AND RECOMMENDATIONS

The project accomplishments during the reporting period are consistant with the objectives of the program. Material procurement and testing are still in process, and the results are incomplete. There is no basis for altering goals.

APPENDIX A - COMPILATION OF PYROELECTRIC MATERIALS AND THEIR CHARACTERISTICS.

TABLE A-1. PYROELECTRIC MATERIALS CHARACTERISTICS

MATERIAL	Curie Temperature T_c °C	Temperature of Measurement T °C	Dielectric Constant ϵ	Frequency of ϵ Measurement F Hz	Spontaneous Polarization P_s C cm^{-2} x 10^{-6}	Pyroelectric Constant dP_s/dT C cm^{-2} °K^{-1} x 10^{-8}	Specific Heat c J cm^{-3} °K^{-1}	Density s g cm^{-3}	A.C. Resistivity (1 KHz) ρ Ω - cm	$(dP_s/dT)\,\epsilon^{-1}$ x 10^{-10}	$(dP_s/dT)\,(\epsilon\,c)^{-1}$ x 10^{-10}	$(dP_s/dT)\,\rho^{1/2}\,c^{-1}$ x 10^{-4}	Reference	COMMENTS
$LiNbO_3$	1200 ± 10	27	30	1K, 100K	50	0.4	2.8	4.65	9.8×10^{10}	1.3	0.46	4.5	N1, P1,	T_c depends on crystal composition; varies from 1150°-1245°C. Transmits 0.4-5.0μ
		100	30	100 K	49.5	0.5				1.7	0.61		S1	
		200	30	100 K	49	0.7				2.3	0.82			
		450	40	100 K	46									
$LiTaO_3$	660,	25	47	1 K	50	1.9	3.16	7.45	$\sim 1 \times 10^{10}$	4.0	1.3	6	G1, G2	T_c depends on crystal composition, varies from 660°-560°C. Transmits 0.5 to 5μ (3μ absorption).
	618 for	250	70	10 K	45	2.1	3.72			3.0	0.81		M1, Y1	
	Ta/Li = 1.1	450	300	10 K	37.7	8.2	3.84			2.7	0.71		I1, G6	
PZT 5A (Clevite)	365	25	1900	1 K	38	4.0	3.1	7.75	4.7×10^{7}	0.21	0.068	0.89	L1, C1	
PZT 4 (Clevite)	328	25	1400	1 K	30	3.7	3.0	7.5	3.2×10^{8}	0.26	0.087	2.2	L1, C1	
PZT HST-41 (Gulton)	270	25	1800	1 K	23	2	3.0	7.6	4.5×10^{7}	0.11	0.037	0.45	L2, G8	
$5PbO \cdot 3GeO_2$	177	50	60	10 K	4.5	1				1.7			I2	
$Gd2\,(MoO_4)_3$	161±2	25	9-12	probably	0.2			4.6						
		100	10	1-10 K	0.15	0.1	2.1			1.0	0.48		K1, R1	Does not exhibit dielectric anomaly at Curie temp. Operates as a laser with Nd^{+3} doping. Ferroelastic.
		143	9.8	"	0.1	0.14	2.1			1.4	0.67		U1, U2	
		151	10.0	"	0.01	0.25	2.1			2.5	1.2		C2, F1	
		159	9.7	"		4.9	8.7			50	5.8			
$NaNO_2$	160	25	8	1 K	7	0.4	2.0	2.1	$>10^{11}$	5	2.5	>6.3	S2, P1	ϵ practically constant to 140°C.

TABLE A-1. PYROELECTRIC MATERIALS CHARACTERISTICS (CONTINUED)

MATERIAL	Curie Temperature T_c °C	Temperature of Measurement T °C	Dielectric Constant ϵ	Frequency of ϵ Measurement F Hz	Spontaneous Polarization P_s C cm^{-2} x 10^{-6}	Pyroelectric Constant dP_s/dT C cm^{-2} °K^{-1} x 10^{-8}	Specific Heat c J cm^{-3} °K^{-1}	Density s g cm^{-3}	A.C. Resistivity (1 KHz) ρ Ω - cm	$(dP_s/dT)\,\epsilon^{-1}$ x 10^{-10}	$(dP_s/dT)\,(\epsilon\, c)^{-1}$ x 10^{-10}	$(dP_s/dT)\,\rho^{1/2}\, c^{-1}$ x 10^{-4}	Reference	COMMENTS
$BaTiO_3$ (single crystal)	120	23			26	5							P1, H1	Absorbs 0.7 to 2μ (I3)
		30			25.5	2							C_3	Cannot be fully poled (S3)
		60	200	1 K	24	7	3.0	6	6×10^6	3.5	1.2	0.57		
		100			20	20								
SBN, x = 0.52[A]	115	25	380	1 K	29.2	6.5	2.1	5.2	1.6×10^8	1.7	0.81	4.0	G3, G4	Transmits 0.5-6.0μ (B5)
SBN, x = 0.33	62	25	1800	1 K	23.3	11			1.2×10^8	0.61	0.29	5.8	B1	
SBN, x= 0.25	47	25	5000	1 K	18	31			7.1×10^6	0.62	0.29	3.9		
NH_4IO_3	85	26	30	1 K		0.3		3.3	2.9×10^8	1			C4	Transmits 0.35 to 2μ. Explodes above 180°C.
TGFB[B]	73	25	11	10 K	3.7	1.3	2.6	1.66		12	4.6		W1, S4	
		50	20	10 K	3.1	4.5	3.1			27	7.1		H2	
DTGS[C]	62.9	25	20	1 K	2.6	2.5	(2.5)	(1.7)	5×10^{10}	12	4.8	22	S5, B3	T_c depends on D_2 substitution for H_2. Only a maximum of 64.8% possible.
		50	80	1 K	1.8	7.5				9.4	3.8		B4	
$TGS_{0.67}\,TGFB_{0.33}$	58.9	25	(35)	1 K	2.9	3.0	(2.5)	(1.66)		9	3.4		B6	TGS:TGFB ratio can be varied to vary T_c
		50			1.75	8.2								
KTN[D]	54	25	900	800	9.3	2				0.22			A1	Transmits out to 6μ. $KTaO_3$ and $KNbO_3$ form solid solution. Parameters depend on composition (C6, T1)
		40	2500	800	8.4	20				1.3				
TGS[E]	49	10	35	1 K	3.0	1.5	2.4			4.4	1.8		P1, D1	Absorbs below 0.24μ (S9) and between 2 to > 400μ (M2). Transmits 0.25-1.8μ. Loss tan. increases below ambient with decreasing temp. (I4). Doping, Xray, and U. V. irradiation affect parameters (Z1, H3, W6, Y2, Y3, S9).
		25	50	1 K	2.75	3.5	2.5	1.65-1.68	1.8×10^{10}	7.0	2.8	19	S6, C5	
		40	150	1 K	2.0	11	2.8			7.3	2.6		K2	

TABLE A-1. PYROELECTRIC MATERIALS CHARACTERISTICS (CONTINUED)

MATERIAL	Curie Temperature T_c °C	Temperature of Measurement T °C	Dielectric Constant ϵ	Frequency of ϵ Measurement F Hz	Spontaneous Polarization P_s C cm^{-2} x 10^{-6}	Pyroelectric Constant dP_s/dT C cm^{-2} °K^{-1} x 10^{-8}	Specific Heat c J cm^{-3} °K^{-1}	Density s g cm^{-3}	A.C. Resistivity (1 KHz) ρ Ω - cm	$(dP_s/dT)\,\epsilon^{-1}$ x 10^{-10}	$(dP_s/dT)\,(\epsilon\, c)^{-1}$ x 10^{-10}	$(dP_s/dT)\,\rho^{1/2}\,c^{-1}$ x 10^{-4}	Reference	COMMENTS
TGS/Se(~15%Se) + additive	49	25	28	10 K		5	2.5		4 x 10^9	17.8	7.1	12.7	P2	Mullard (U.K.) Development; Material does not depole.
TGS/Se(~5%Se)	47	25	26	10 K		4.1	2.5		5 x 10^9	15.8	6.3	11.7	P2	Mullard (U. K.) Development; Material does not depole.
DTGSe(F)	34.5	25	(100)		3.2	7.5	(2.3)			7.5	3.3		M3	Will operate up to 95% relative humidity (C1). Has rather flat response over a wide temp. range (B1, N3).
TGSe(G)	22.2	0			3.0		2.1						H2, M3,	
		15	(100)		2.6	13	2.3			13	5.7		S7, S8, G7	
$Li_2SO_4 \cdot H_2O$	(M)	25	10.3	1 K	0.8	0.82	2.06			7.8	9.5		L1, A2	
		50	(10)		1					(10)	(12)		W2	
$Li_2SeO_4 \cdot H_2O$		20				0.57							A2	
		79				0.65								
Polyvinylidene fluoride (CH_2CF_n)	not known, softens at 150°C melts at 177°C	25	11		2	0.24			6.7 x 10^9	2.2	0.9	0.82	B2, G5	Transmits 0.4-2μ absorbs 3-300μ T_c (if it exists) may be near the melting point (N2)

TABLE A-1. PYROELECTRIC MATERIALS CHARACTERISTICS (CONTINUED)

MATERIAL	Curie Temperature T_c °C	Temperature of Measurement T °C	Dielectric Constant ϵ	Frequency of ϵ Measurement F Hz	Spontaneous Polarization P_s C cm^{-2} x 10^{-6}	Pyroelectric Constant dP_s/dT C cm^{-2} °K^{-1} x 10^{-8}	Specific Heat c J cm^{-3} °K^{-1}	Density s g cm^{-3}	A.C. Resistivity (1 KHz) ρ Ω - cm	$(dP_s/dT)\,\epsilon^{-1}$ x 10^{-10}	$(dP_s/dT)\,(\epsilon\, c)^{-1}$ x 10^{-10}	$(dP_s/dT)\,\rho^{1/2}\, c^{-1}$ x 10^{-4}	Reference	COMMENTS
SbSI	22	0	2200		22								F2	Also photoconductive (U3)
		10	2500		15	60	2.38	8.2		2.4	1.0		W2	
		15	3000		12	100				3.3	1.4			
GASH[H]	(M)	25	6	1 K	0.35	0.15	~ 1		9×10^{10}	2.5	2.5	4.5	H4, P1, N3	Ge isomorph (for Al) SeO_4 isomorph (for SO_4) (Ge and SeO_4) isomorph (for Al and SO_4). Similar performance (H4).
GUL[I]		25	4.6	1 K		0.62	~1.5		4×10^{11}	13.5	9	26	P1	
EDT[J]		25	7.0	1 K		0.2	~1		$>10^{11}$	3	3	>6	P1	dP_s/dT is constant from 20° to 80°C (N3)
Colemanite[K]	-7	-10	60	1 K	0.29	5.4	0.58	2.42		9	15.5		W3, C7	Depending on purity, T_c of 2.5C is also reported (D2). Synthetic strontium isomorphs (polycrystalline) have been grown (W4, W5).
		-20	12	1 K	0.46	1.2				10	17			
KDDP[L]	-50±2	-60	50	1 K	4.0	10		2.36	8.6×10^7	20			M4, A3	Transmits 0.2 to 2μ.
(NH_2CH_2COOH) HNO_3	-67	-77	50	10 K	0.6	5	2.0	1.58		10	5		P3	
		-190	15	10 K	1.5	0.13				0.87				
$CS(NH_2)_2$ (Thiourea)	-104	-178	400		3.4	1		1.40		0.25			G9	
KH_2PO_4 (KDP)	-150	-178	2500	1K	4.8	3.3	0.94	2.34	7.2×10^6	0.13	0.14	1	B7, A3, D3, K3, S10	Transmits 0.2 to 2μ.

TABLE A-I. PYROELECTRIC MATERIALS CHARACTERISTICS (CONTINUED)

NOTES

Values in parentheses are based on assumptions.

A SBN = $Sr_{1-x}Ba_xNb_2O_6$

B TGFB = $(NH_2CH_2COOH)_3H_2BeF_4$

C DTGS = $(ND_2CH_2COOD)_3 D_2SO_4$

D KTN = $KTa_{0.57}Nb_{0.43}O_3$

E TGS = $(NH_2CH_2COOH)_3 H_2SO_4$

F DTGSe = $(ND_2CH_2COOH)_3 D_2SeO_4$

G TGSe = $(NH_2CH_2COOH)_3 H_2SeO_4$

H GASH = $(CN_3H_6)Al(SO_4)_2 \cdot 6H_2O$

I GUL = Glucuronolactone = $CO \cdot (CHOH)_2 \cdot CH(O) \cdot CHOH \cdot CHO$

J EDT = $C_2 H_4 (NH_3)_2 C_4H_4O_6$

K Colemanite = $2CaO \cdot 3B_2 O_3 \cdot 5H_2O$

L KDDP = $KD_2 PO_4$ (~90%D_2)

M Decomposes before T_c can be measured.

APPENDIX B - MEASURED DATA ON SELECTED PYROELECTRIC MATERIALS -
OPTICAL TRANSMISSION - OPTICAL REFLECTANCE

TGFB

DTGS

$TGS_{0.88} - TGFB_{0.12}$

TGS

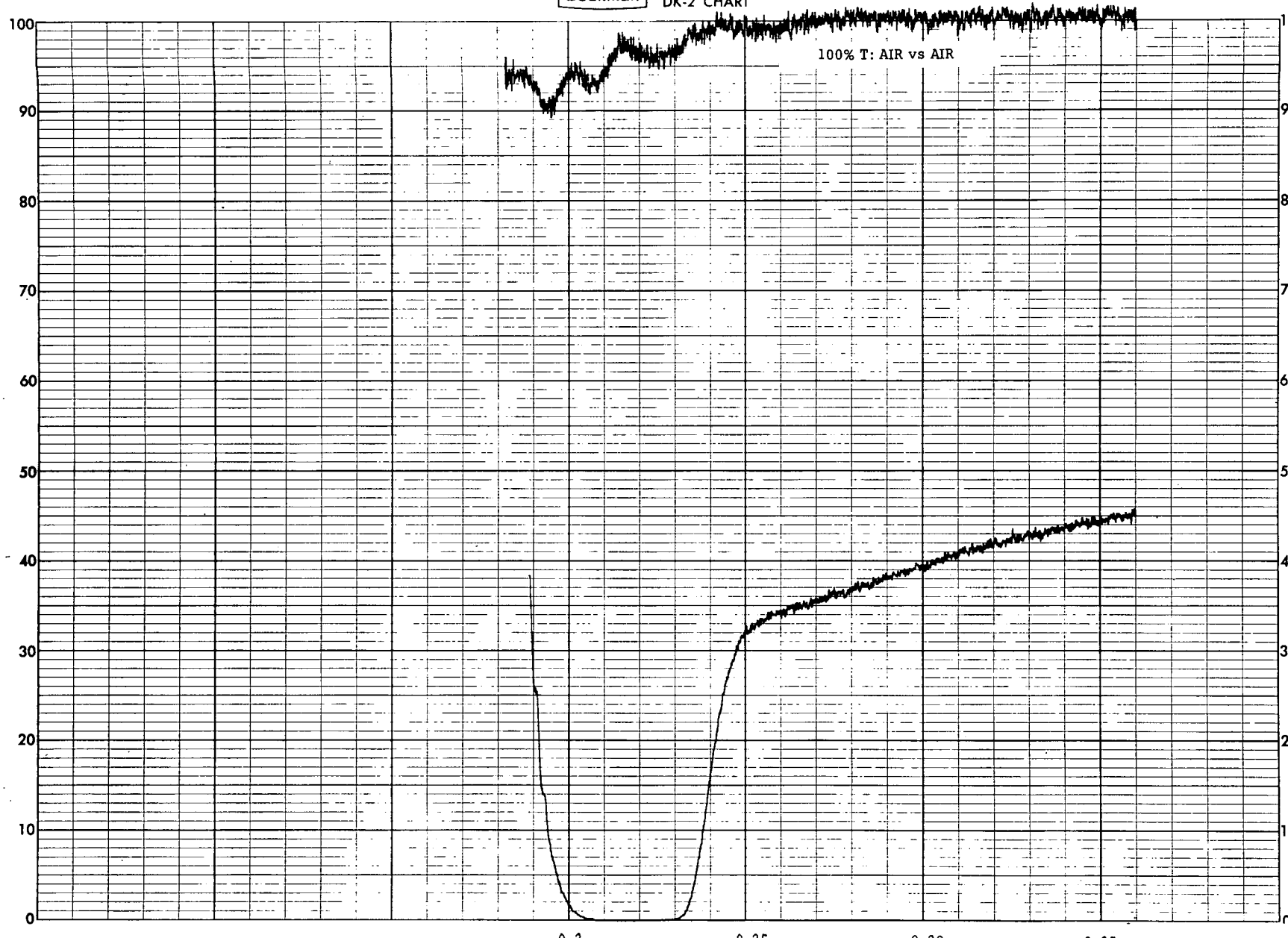
$Li_2 SO_4 \cdot H_2O$

Polyvinylidene Fluoride

Printed in U.S.A. 69TW740

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGFB

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

ANALYST AWB

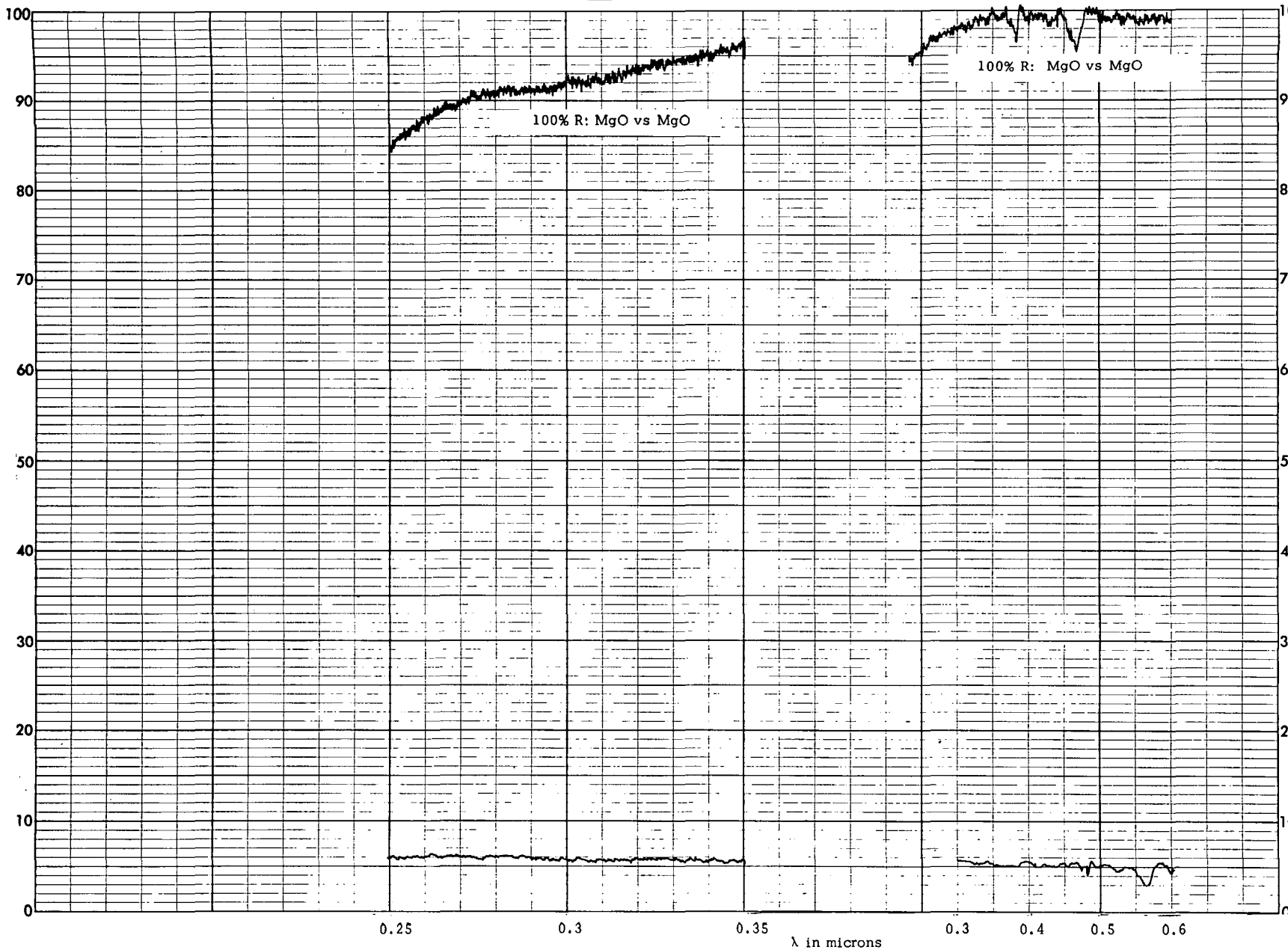
DATE 11-15-71

B-1

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGFB

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100%R

SENS 150

PERIOD 0.6SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

ANALYST AWB

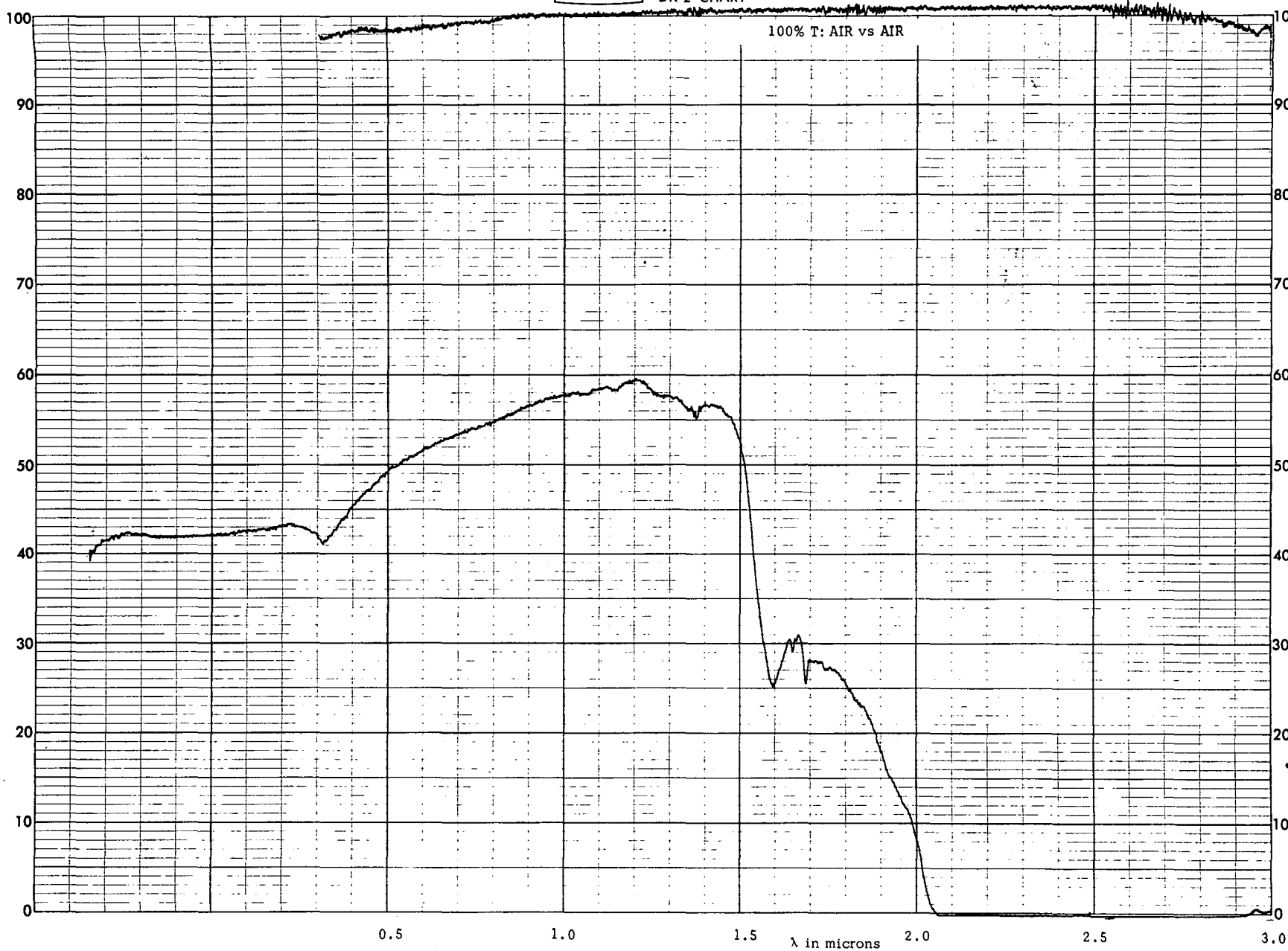
DATE 11-15-71

B-2

Printed in U.S.A. 69TW740 9:0

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGFB

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W x

H_2

D_2

DETECTOR: PM

PbS x

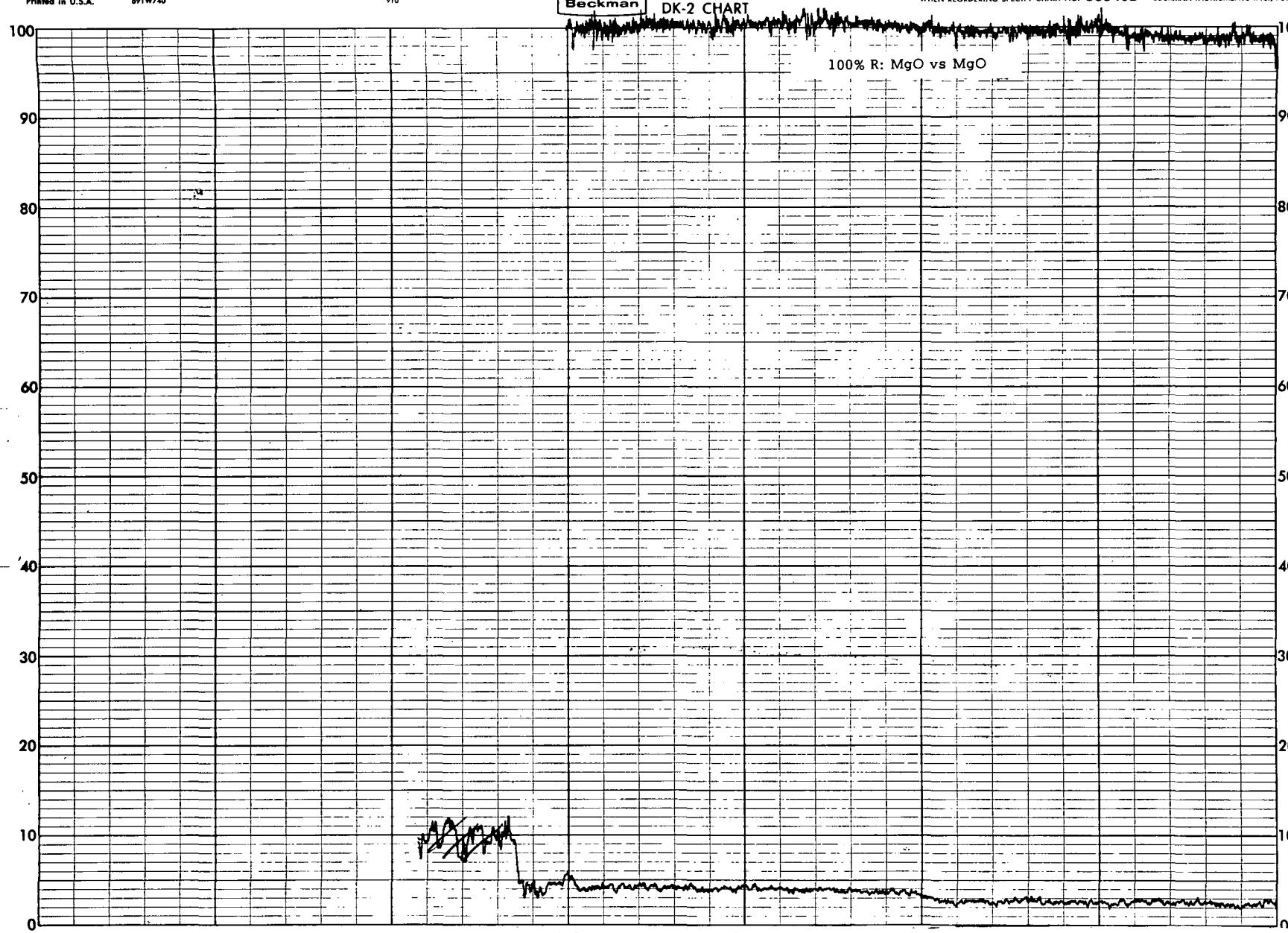
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGFB

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100%R

SENS 150

PERIOD 0.2 SEC

SOURCE: W x

H_2

D_2

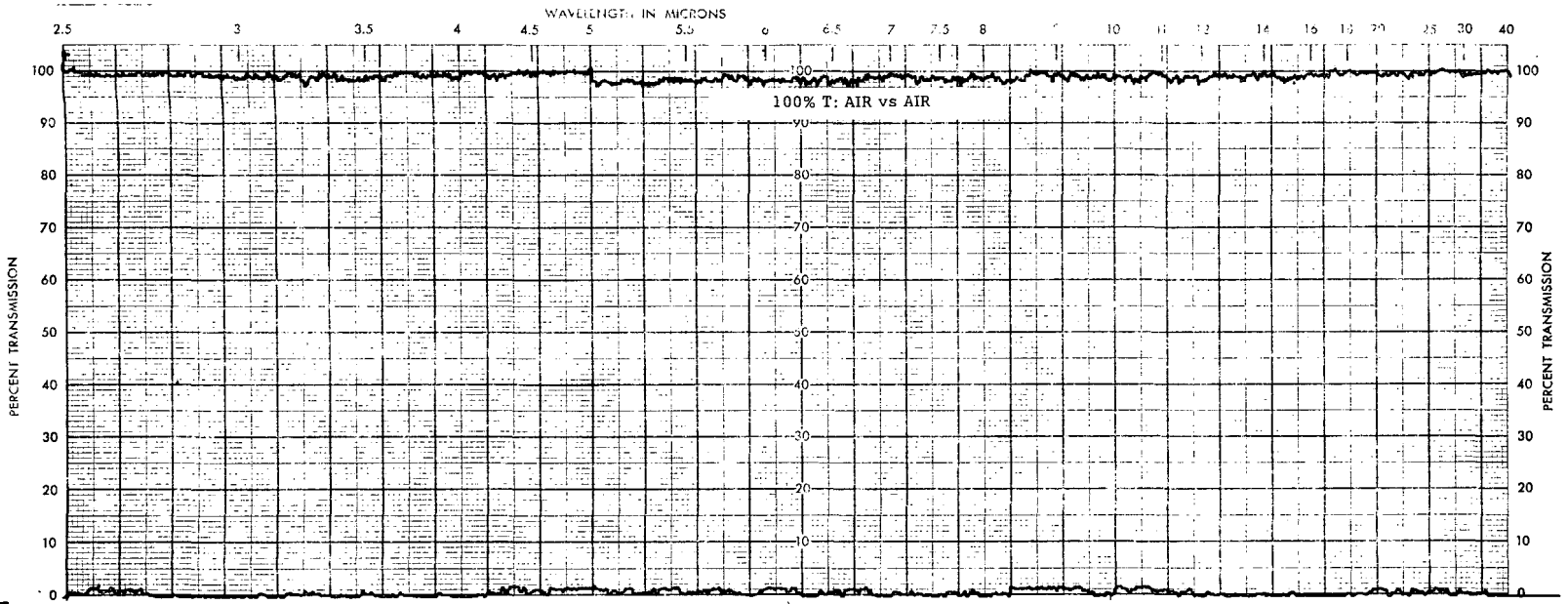
DETECTOR: PM

PbS x

ANALYST AWB

DATE 11-15-71

B-4



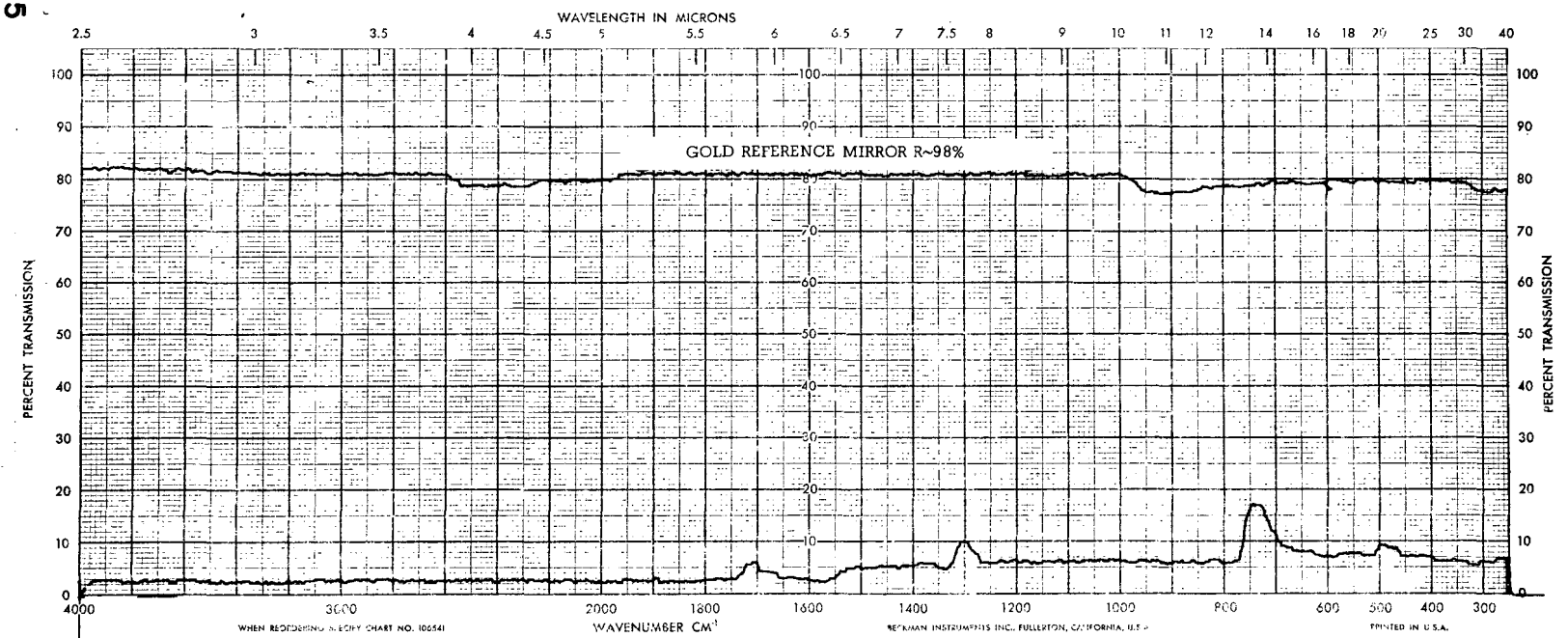
SPECTRUM NO.
DATE 11-15-71
SAMPLE TGFB

SOURCE BEC
STRUCTURE
IR-20 TRANSMISSION
AT NORMAL INCIDENCE

PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST AWB

Beckman®



SPECTRUM NO.
DATE 11-15-71
SAMPLE TGFB

SOURCE
STRUCTURE
IR-20 SPECULAR REFLECTANCE
AT 30° INCIDENCE

PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST AWB

Beckman®

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Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.

SAMPLE DTGS

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

ANALYST AWB

DATE 11-15-71

B-9

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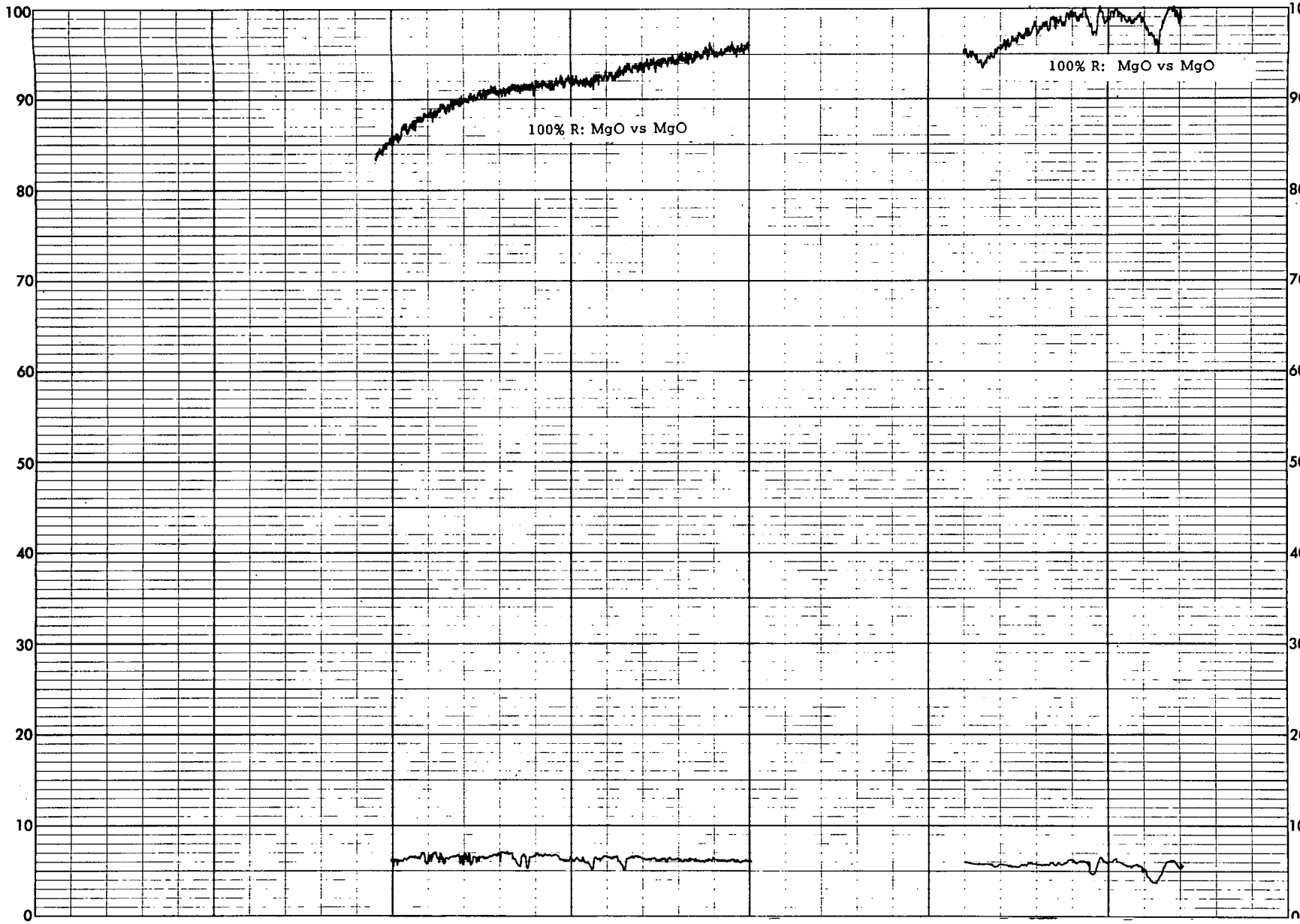
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE DTGS

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.6 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

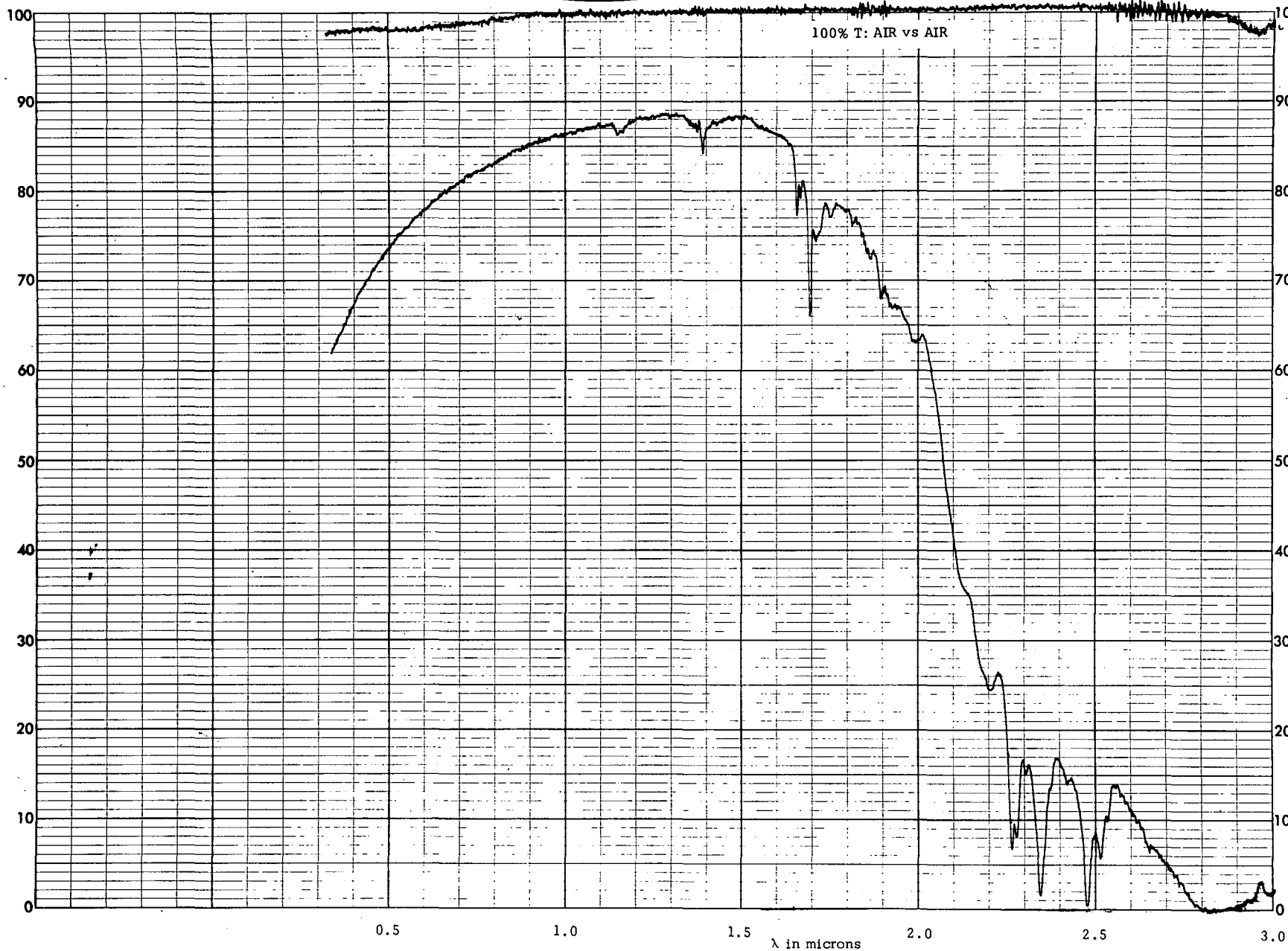
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE DTGS

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W x

H_2

D_2

DETECTOR: PM

PbS x

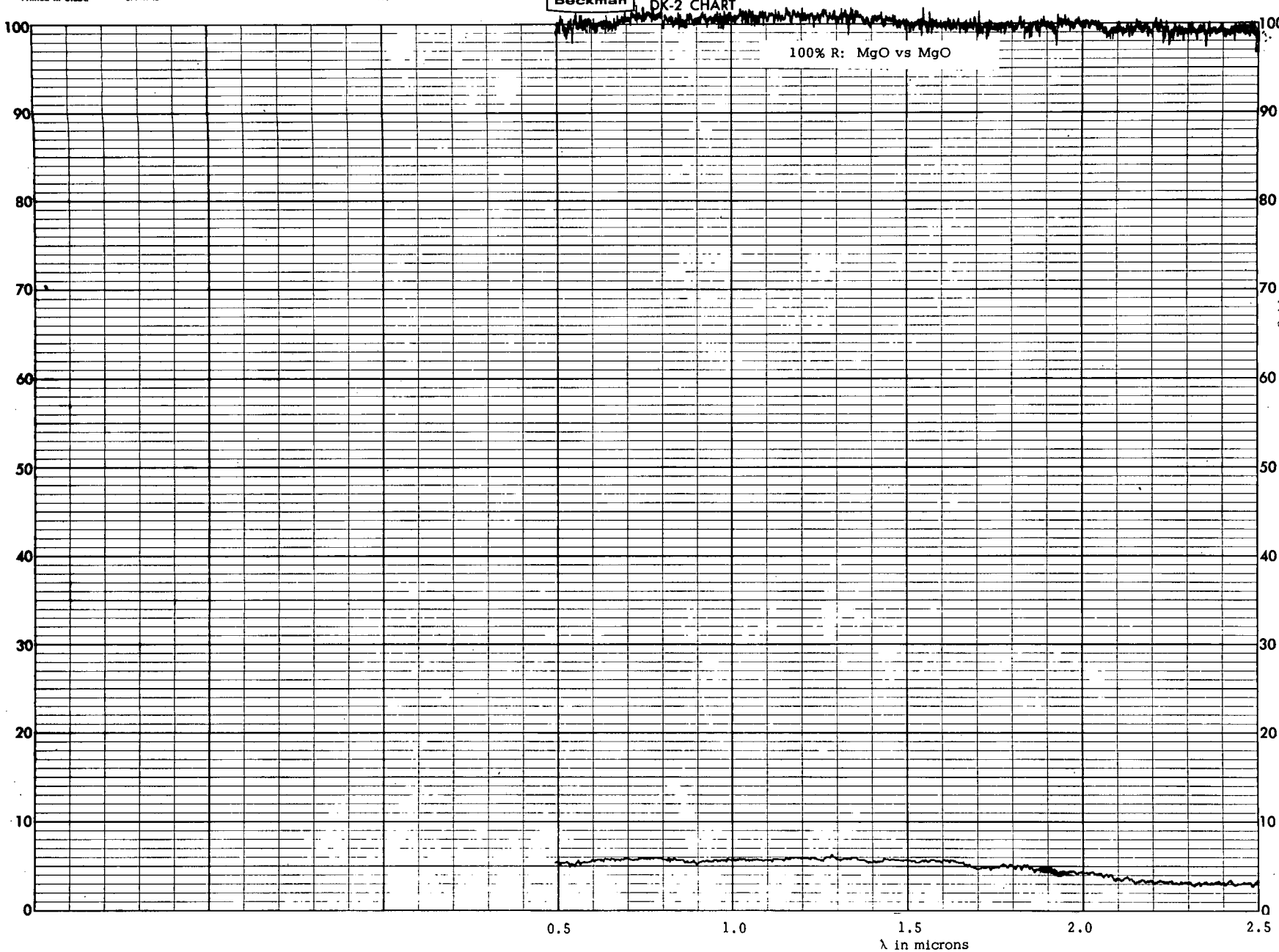
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE DTGS

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.2SEC

SOURCE: W x

H_2

D_2

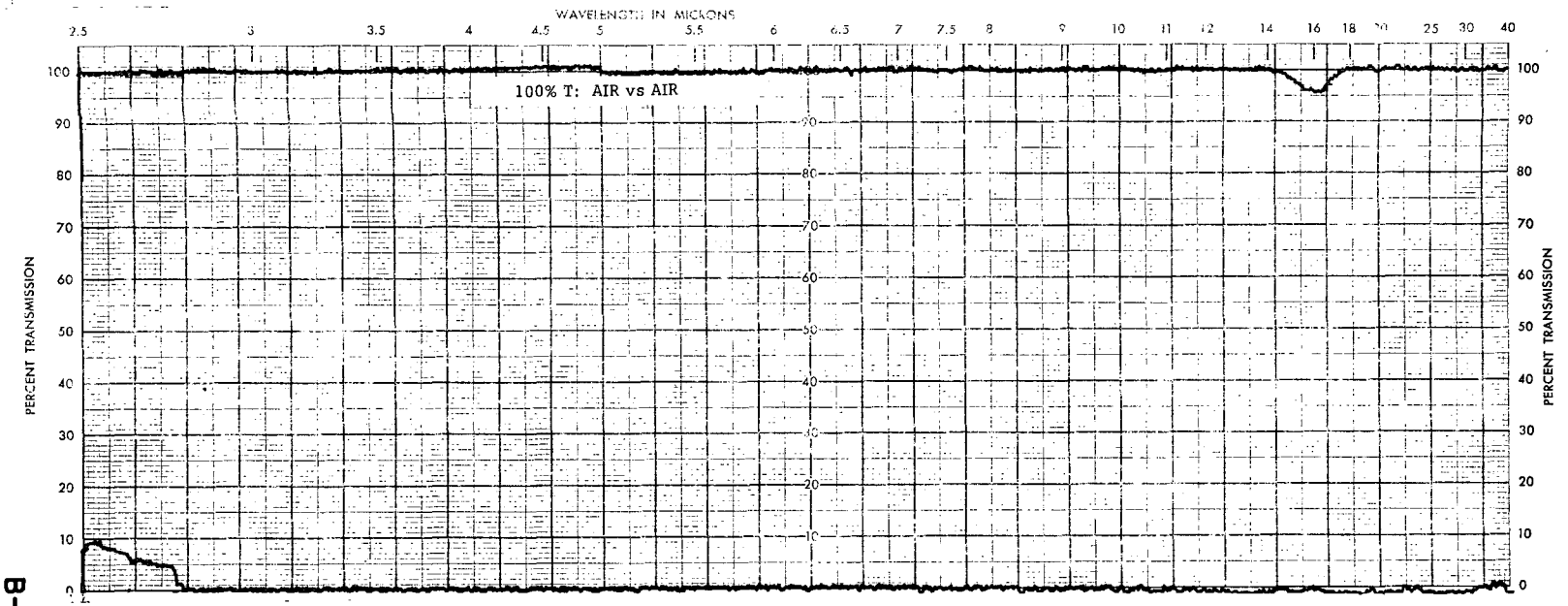
DETECTOR: PM

PbS x

ANALYST AWB

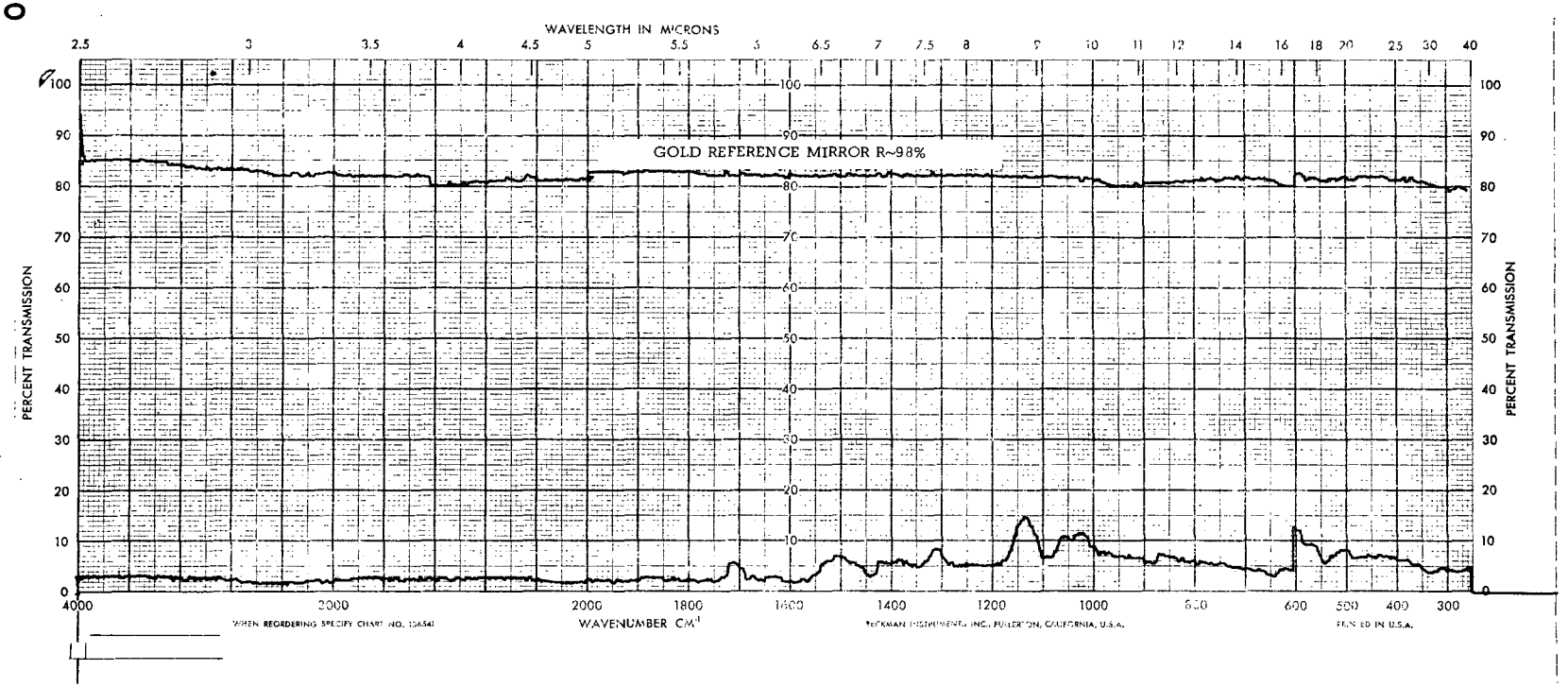
DATE 11-15-71

B-10



SPECTRUM NO.
DATE
SAMPLE DTGS
SOURCE BEC
STRUCTURE
IR-20 TRANSMISSION AT NORMAL INCIDENCE
PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS
ANALYST AWB

Beckman®



SPECTRUM NO.
DATE 11-15-71
SAMPLE DTGS
SOURCE BEC
STRUCTURE
IR-20 SPECULAR REFLECTANCE AT 30° INCIDENCE
PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS
ANALYST AWB

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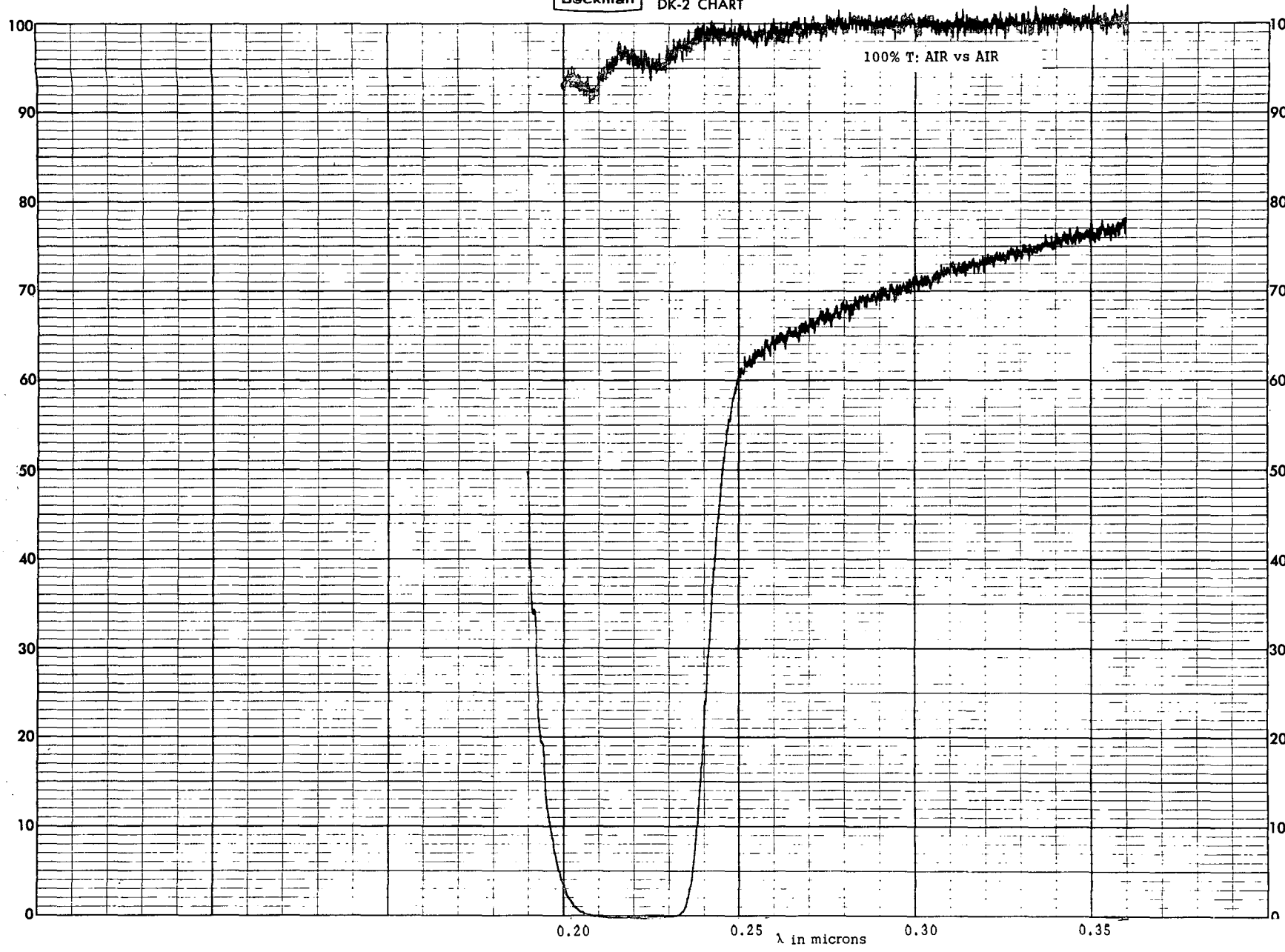
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE

TGS . TGFB
0.88 .12

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

ANALYST AWB

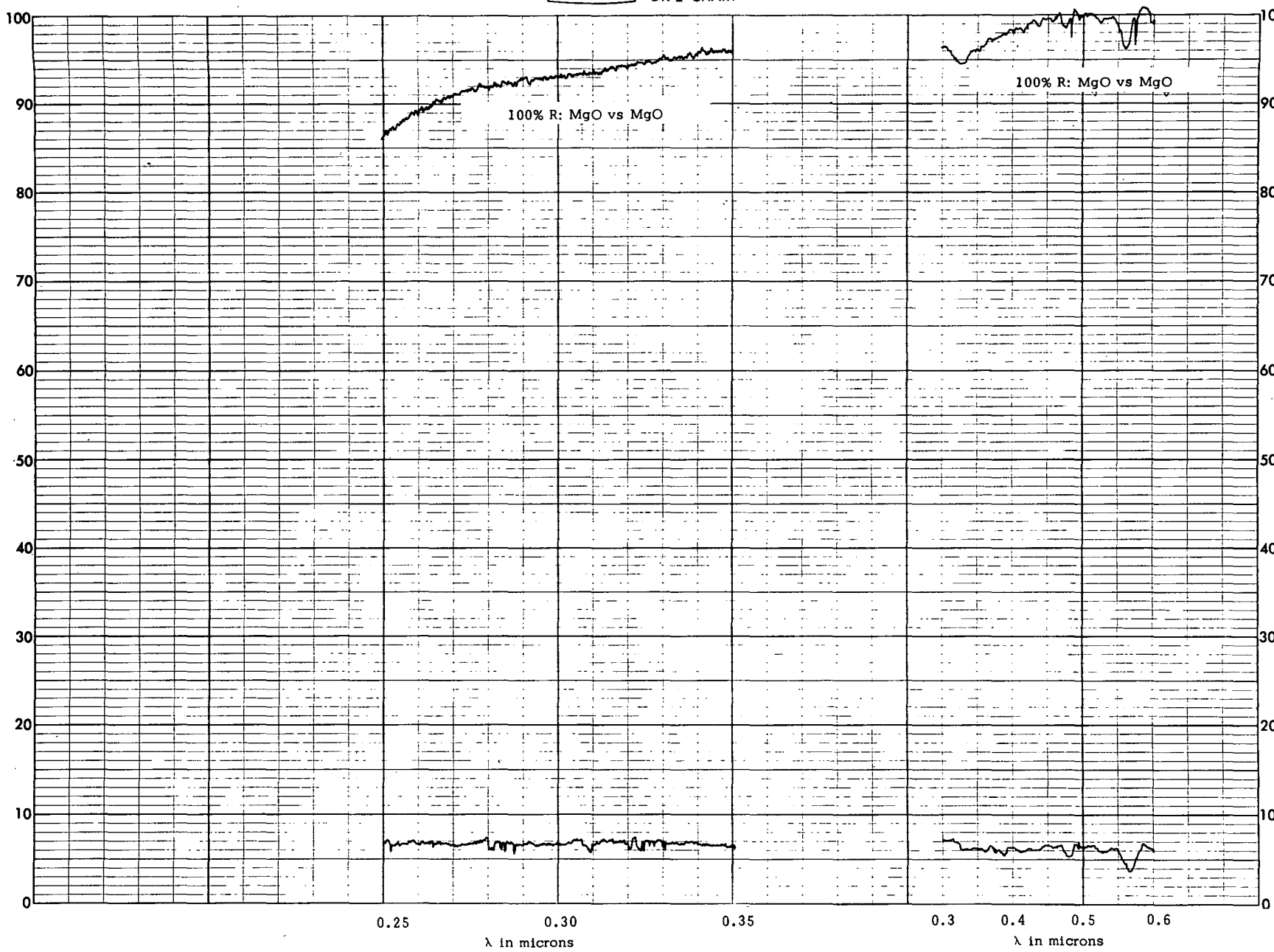
DATE 11-15-71

B-11

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE

TGS .88 . TGFB .12

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.6 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

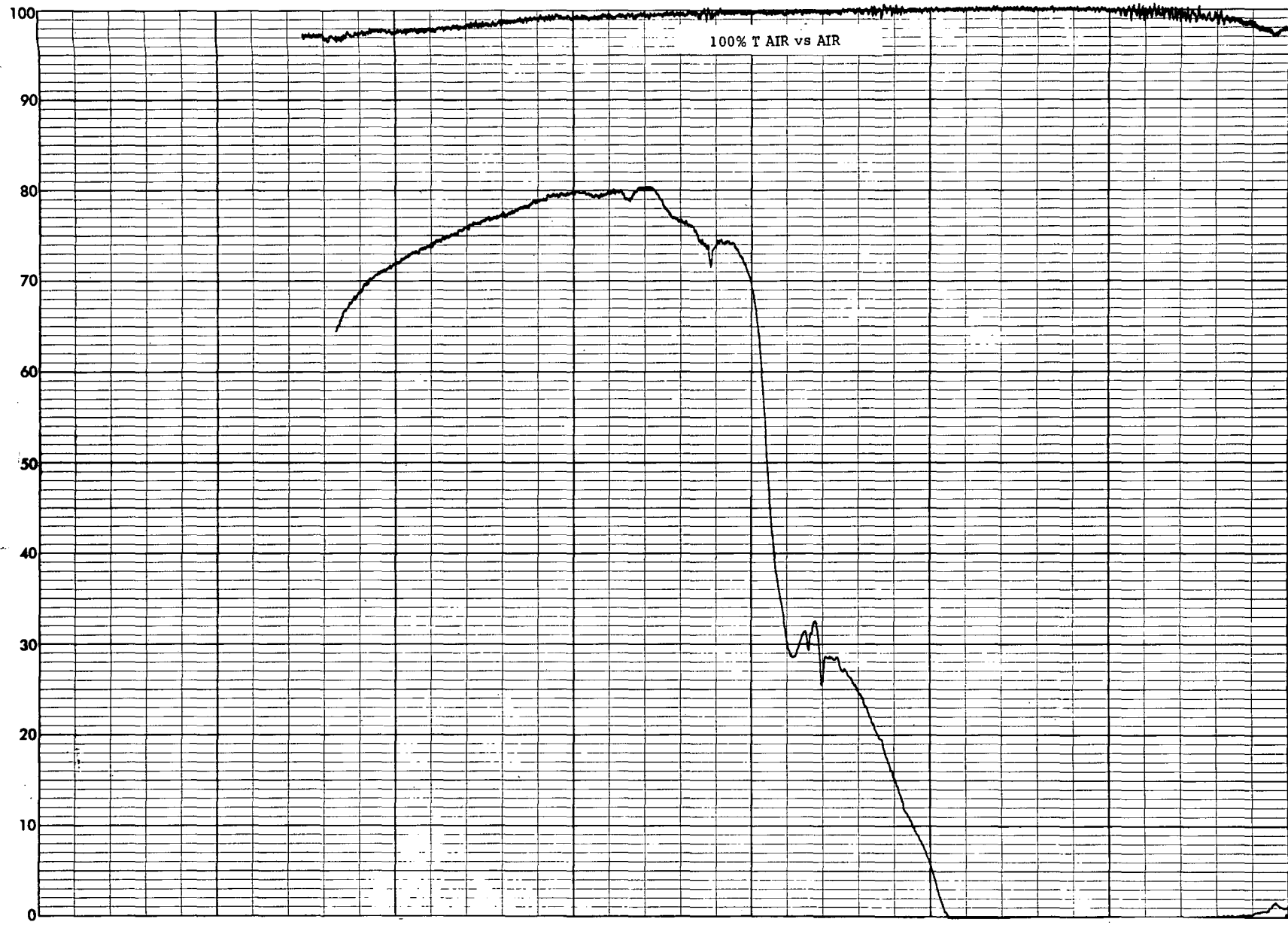
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE_____

TGS .88 . TGFB .12

PATH 0.1 cm

ORIGIN_____

SOLVENT_____

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100%T

SENS 100

PERIOD 0.2 SEC

SOURCE: W x

H_2_____

D_2_____

DETECTOR: PM_____

PbS x

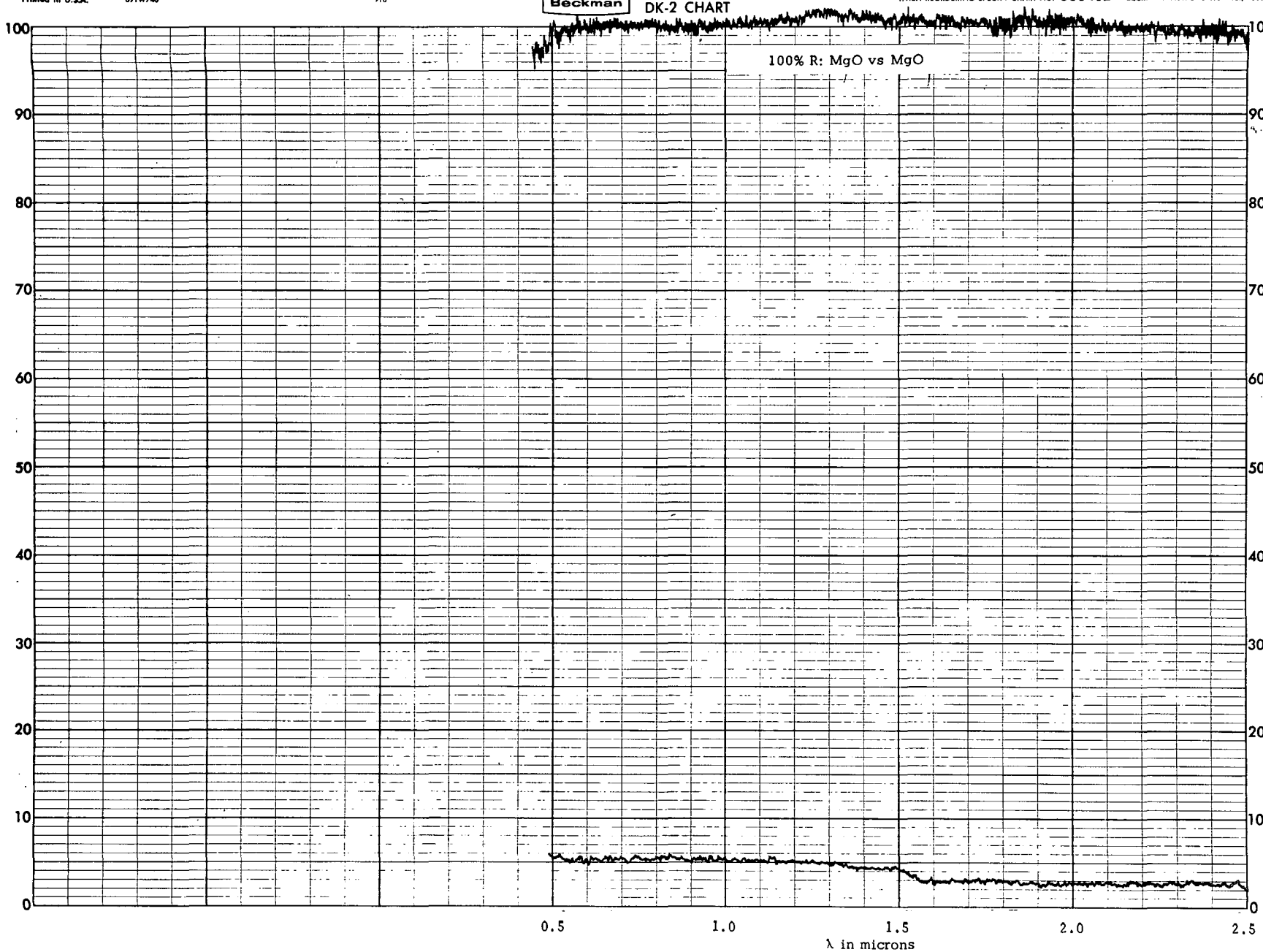
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE

TGS .88 . TGFB .12

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100%R

SENS 150

PERIOD 0.2 SEC

SOURCE: W x

H_2

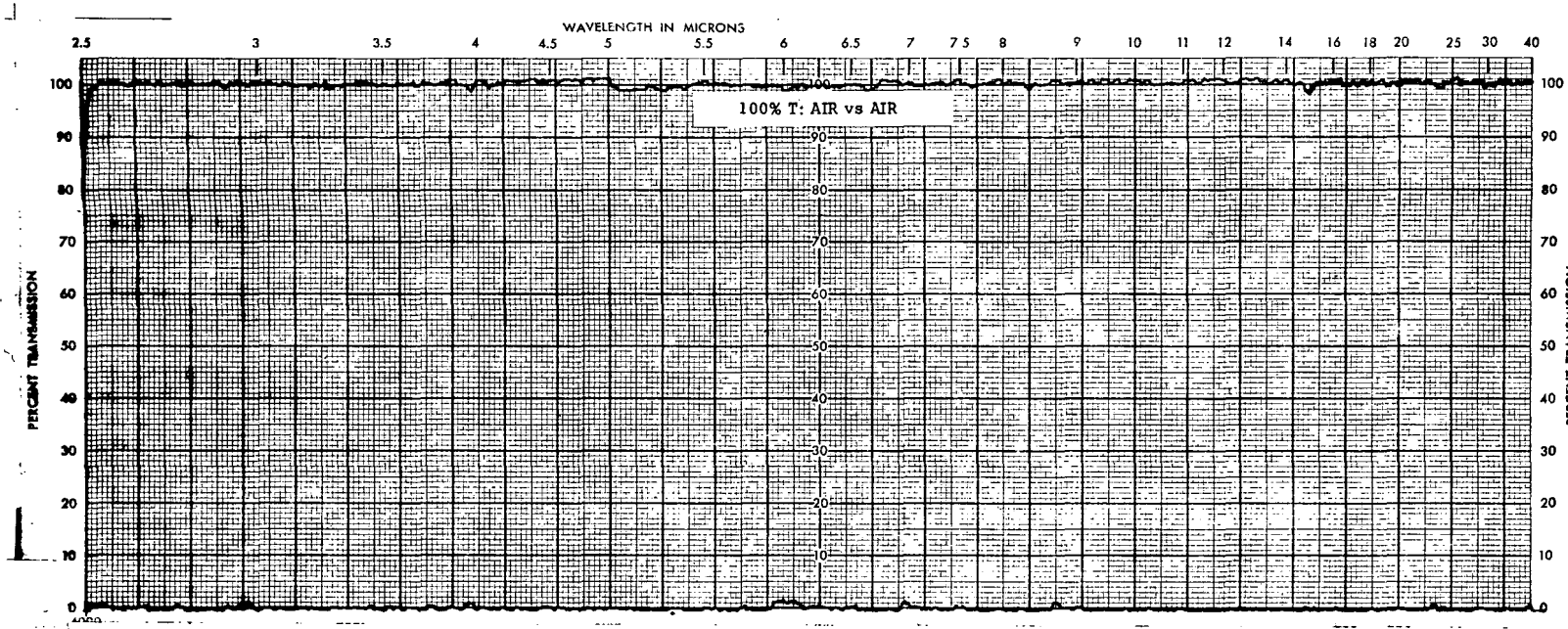
D_2

DETECTOR: PM

PbS x

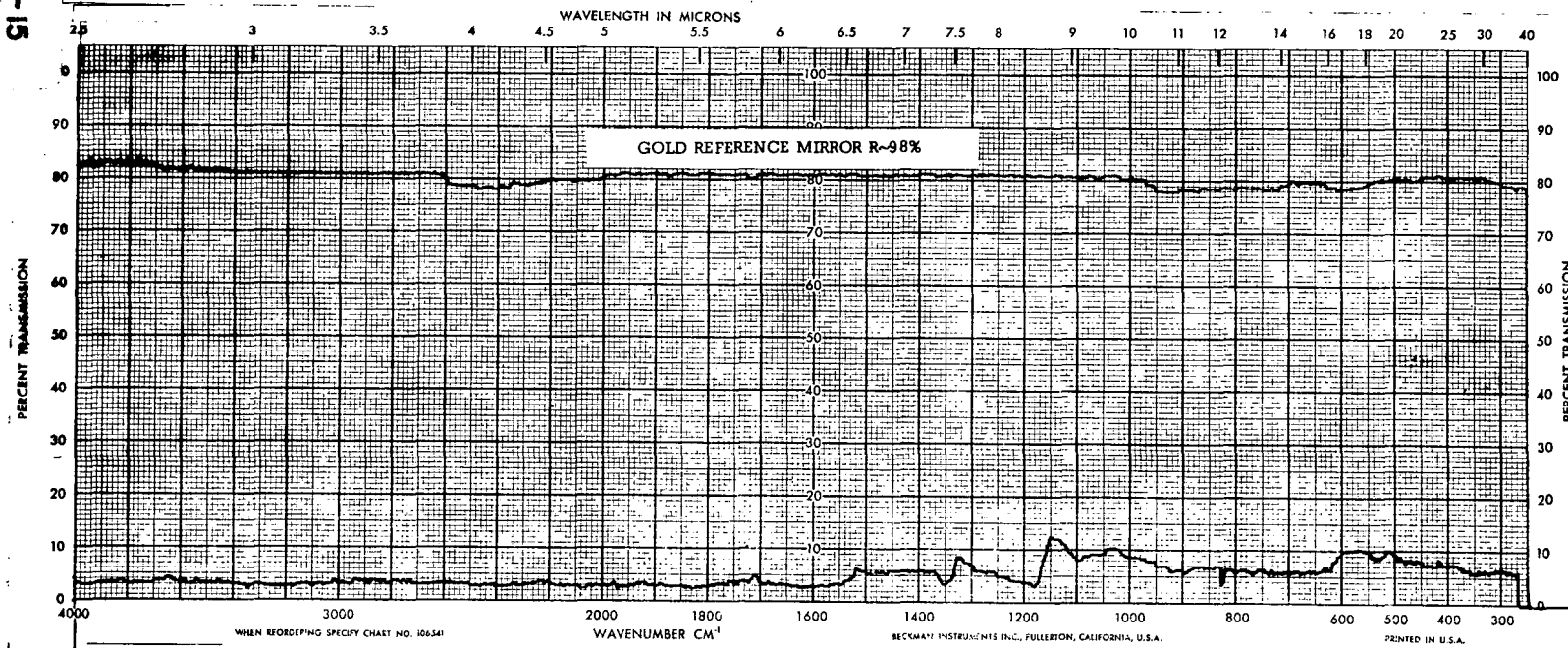
ANALYST AWB

DATE 11-15-71



SPECTRUM NO.
DATE 11-15-71
SAMPLE TGS .88 / TGFB .12
SOURCE BEC
STRUCTURE
IR-20 TRANSMISSION AT NORMAL INCIDENCE
PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS
ANALYST AWB

Beckman®



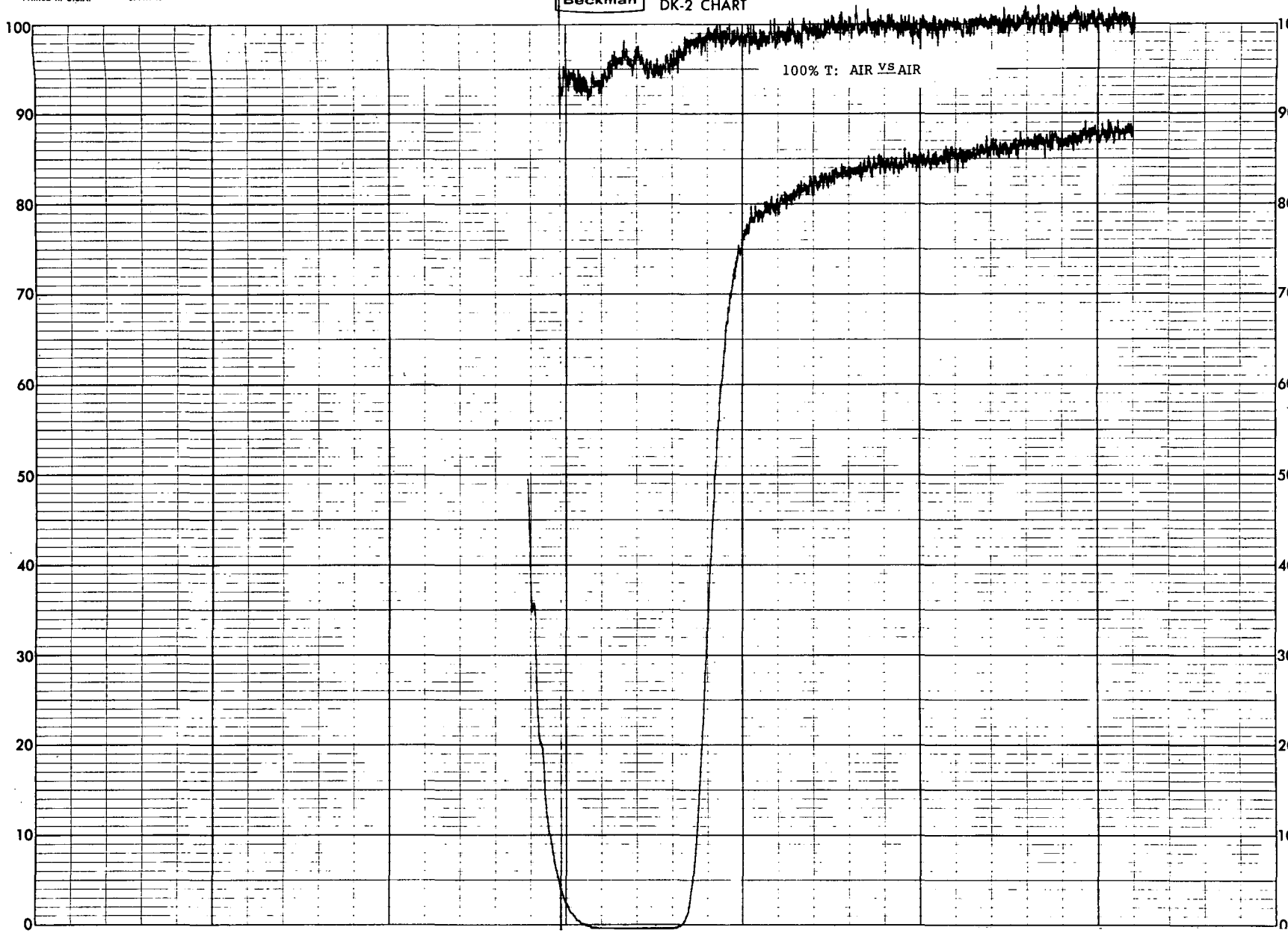
SPECTRUM NO.
DATE 11-15-71
SAMPLE TGS .88 / TGFB .12
SOURCE BEC
STRUCTURE
IR-20 SPECULAR REFLECTANCE AT 30° INCIDENCE
PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS
ANALYST AWB

Beckman®

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGS

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENC

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

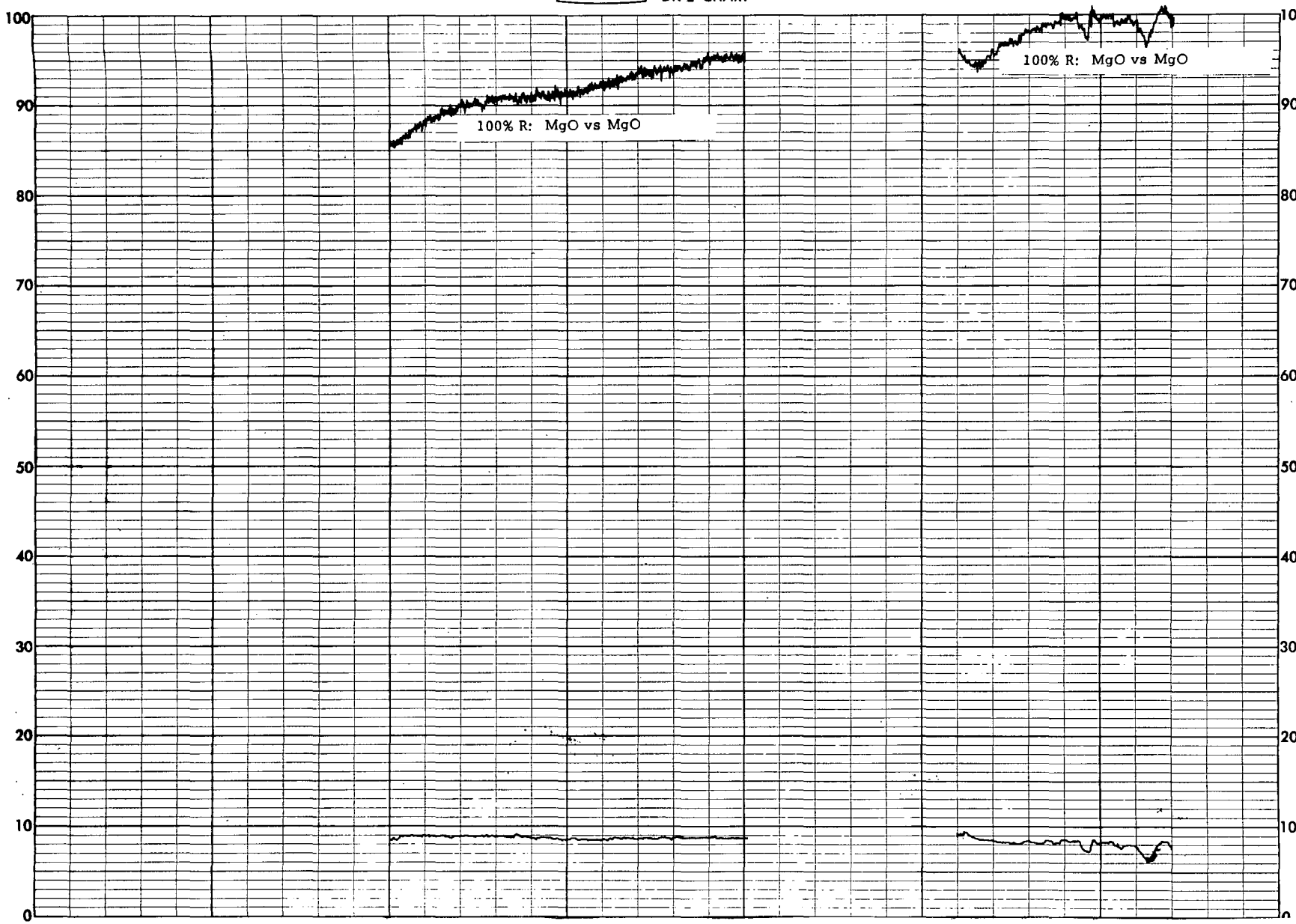
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGS

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.6 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

ANALYST AWB

DATE 11-15-71

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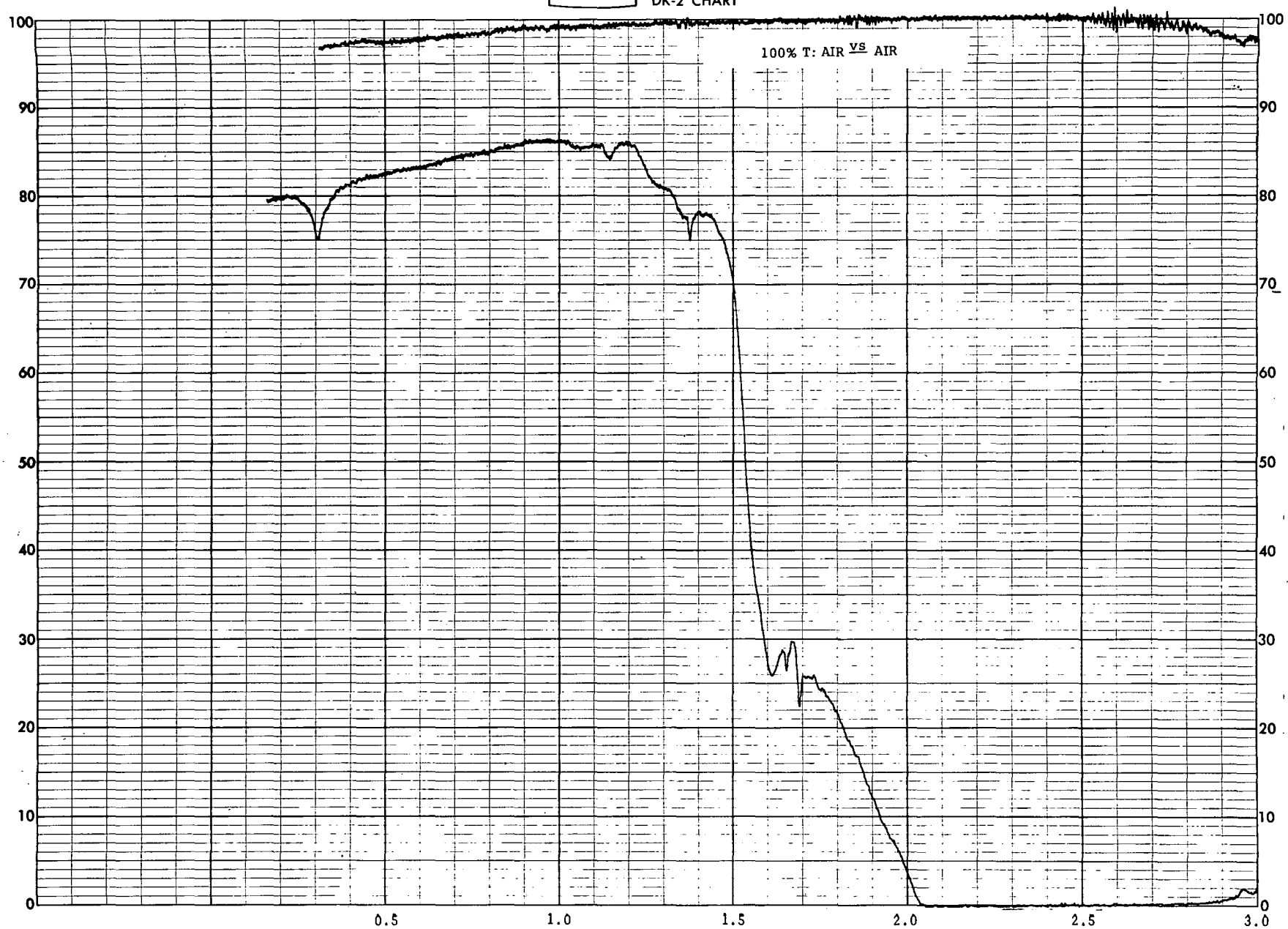
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGS

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDEN

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W x

H_2

D_2

DETECTOR: PM

PbS x

ANALYST AWB

DATE 11-15-71

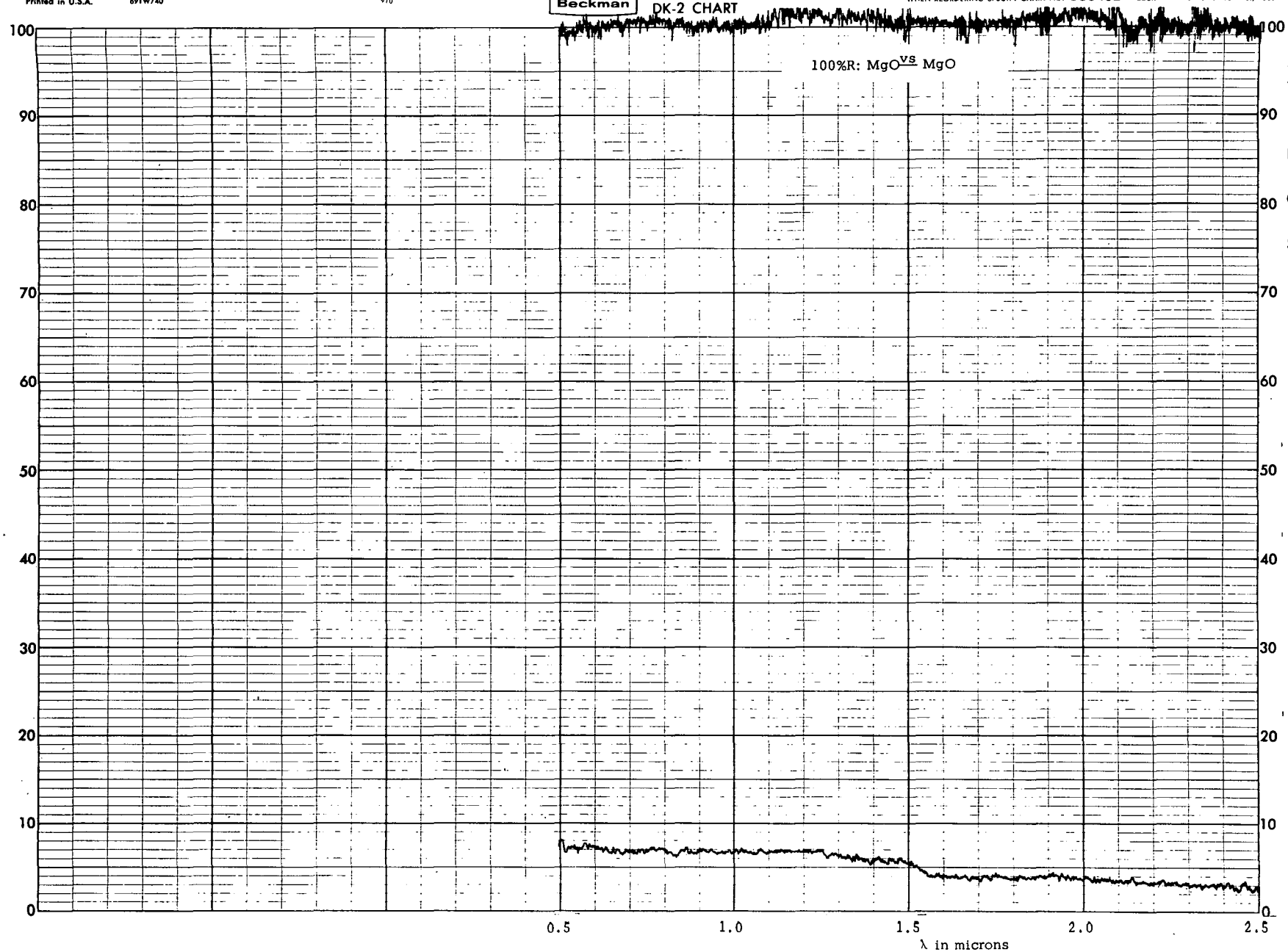
Beckman Instruments, Inc.

B-18

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE TGS

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTION AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.2 SEC

SOURCE: W x

H_2

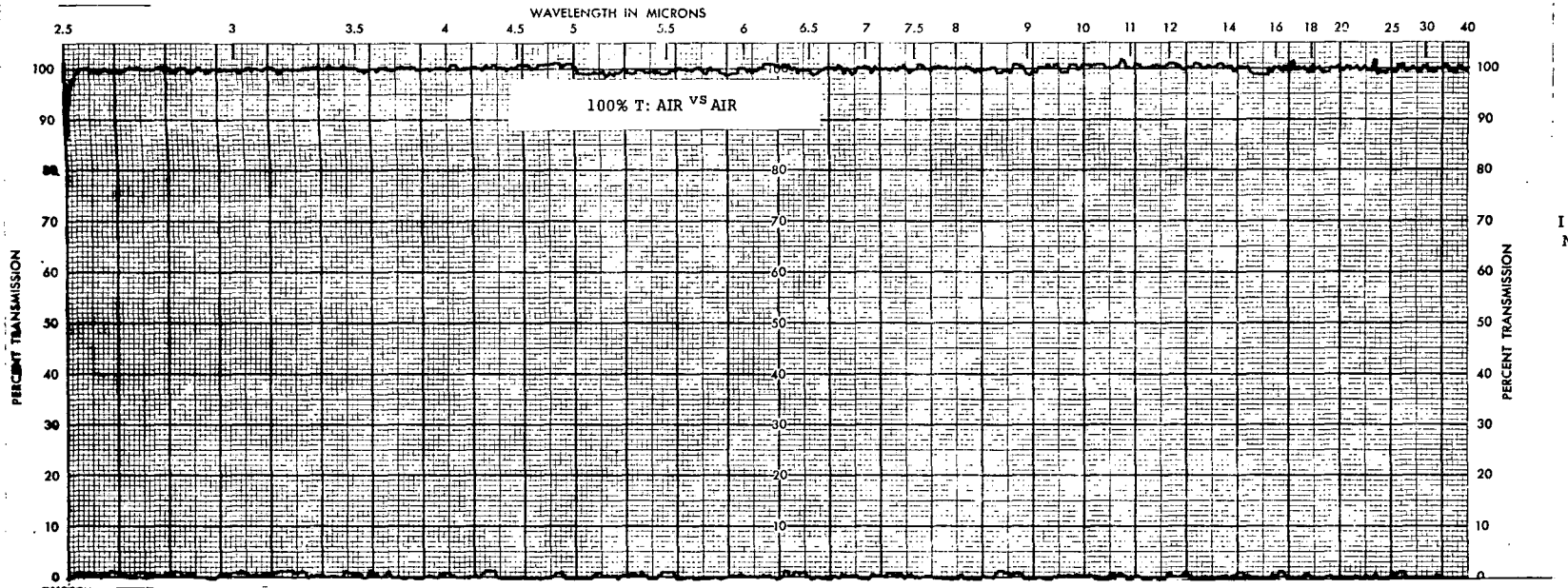
D_2

DETECTOR: PM

PbS x

ANALYST AWB

DATE 11-15-71



SPECTRUM NO.
DATE 11-15-71
SAMPLE TGS

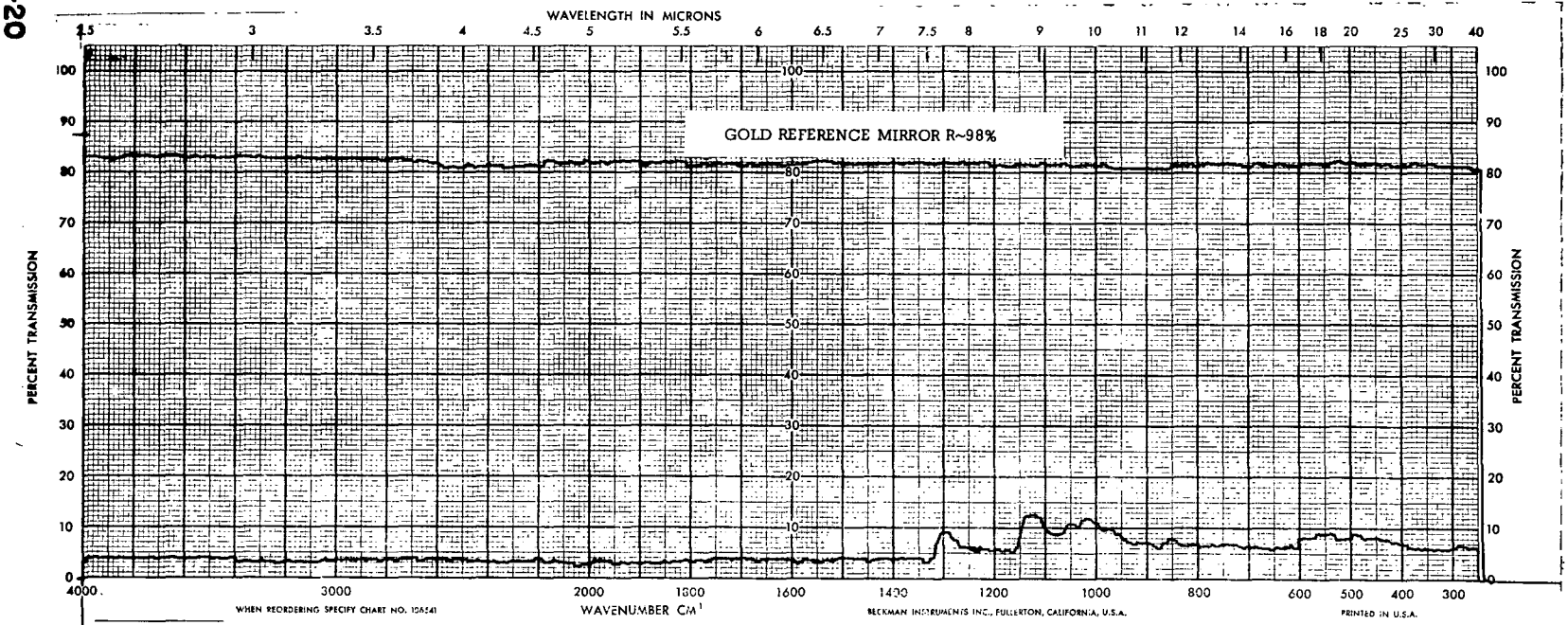
SOURCE BEC
STRUCTURE
IR-20 TRANSMISSION AT NORMAL INCIDENCE

PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST AWB

Beckman®

B-20



SPECTRUM NO.
DATE 11-15-71
SAMPLE TGS

SOURCE BEC
STRUCTURE
IR-20 SPECULAR REFLECTANCE AT 30° INCIDENCE

PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST AWB

Beckman®

WHEN REORDERING SPECIFY CHART NO. 106541
BECKMAN INSTRUMENTS INC., FULLERTON, CALIFORNIA, U.S.A.
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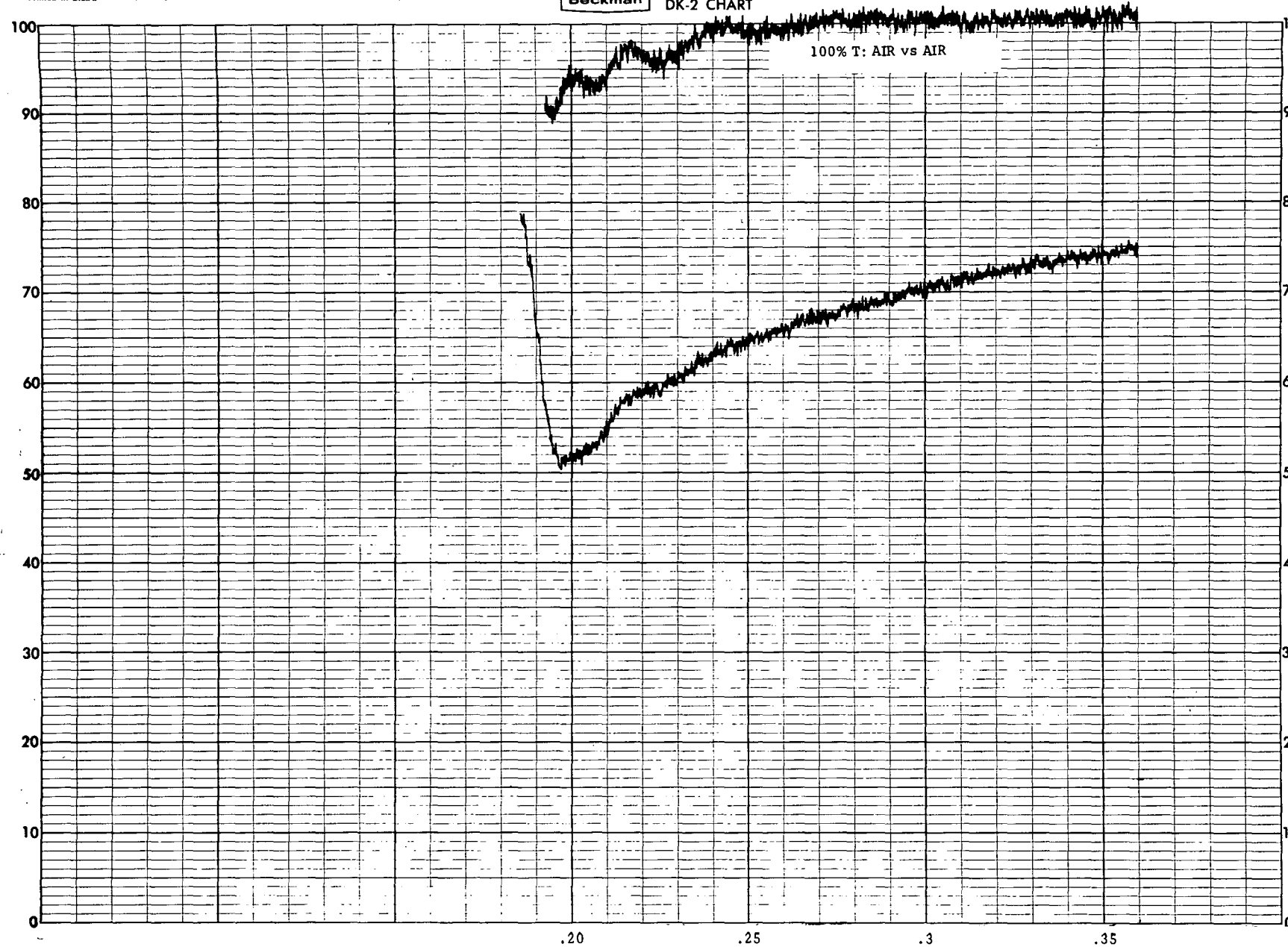
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE $Li_2SO_4 \cdot H_2O$

PATH 0,1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W

H_2

D_2 X

DETECTOR: PM X

PbS

ANALYST AWB

DATE 11-15-71

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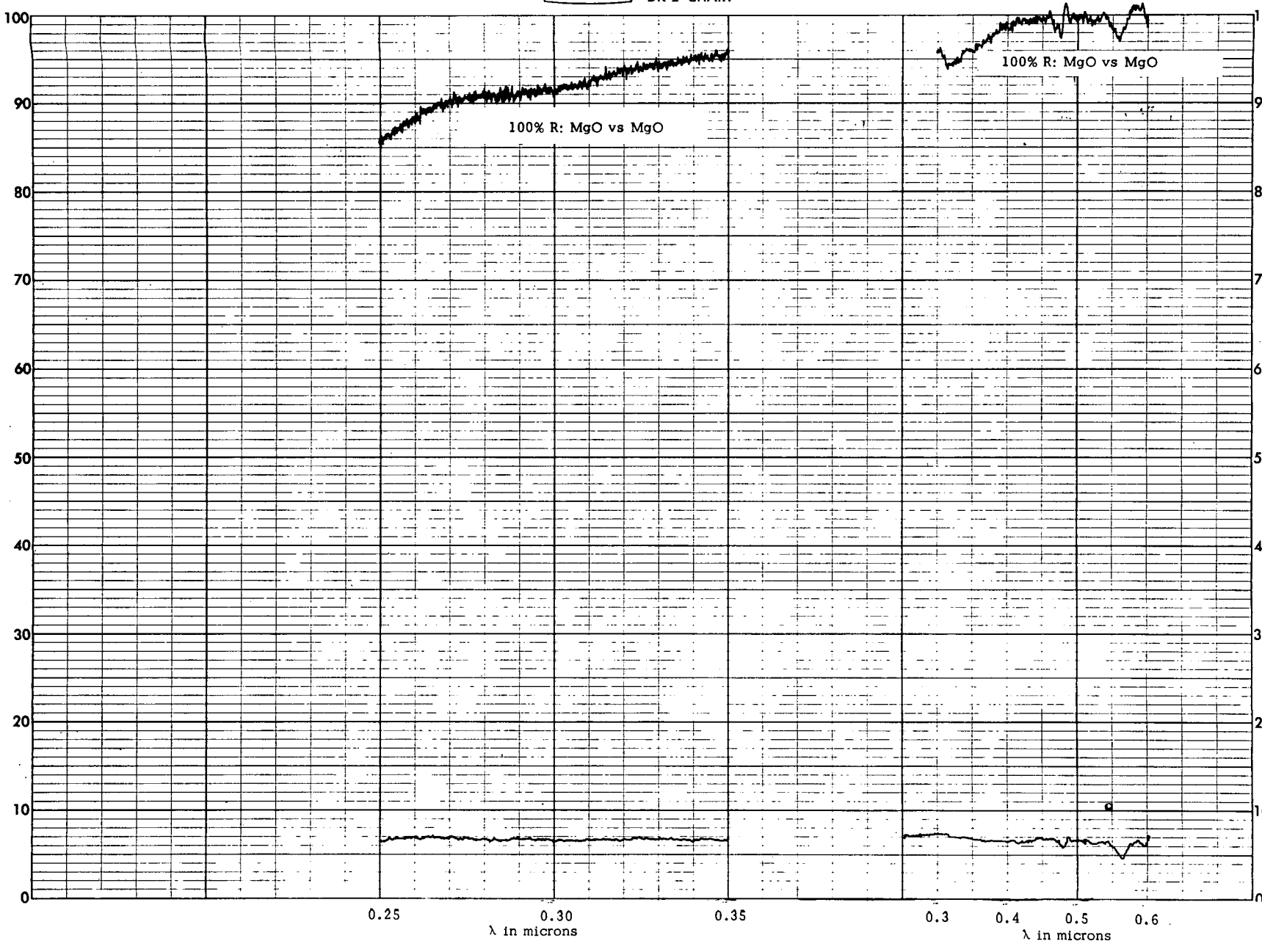
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE

$Li_2SO_4 \cdot H_2O$

PATH 0.1 cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.6 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM. x

PbS

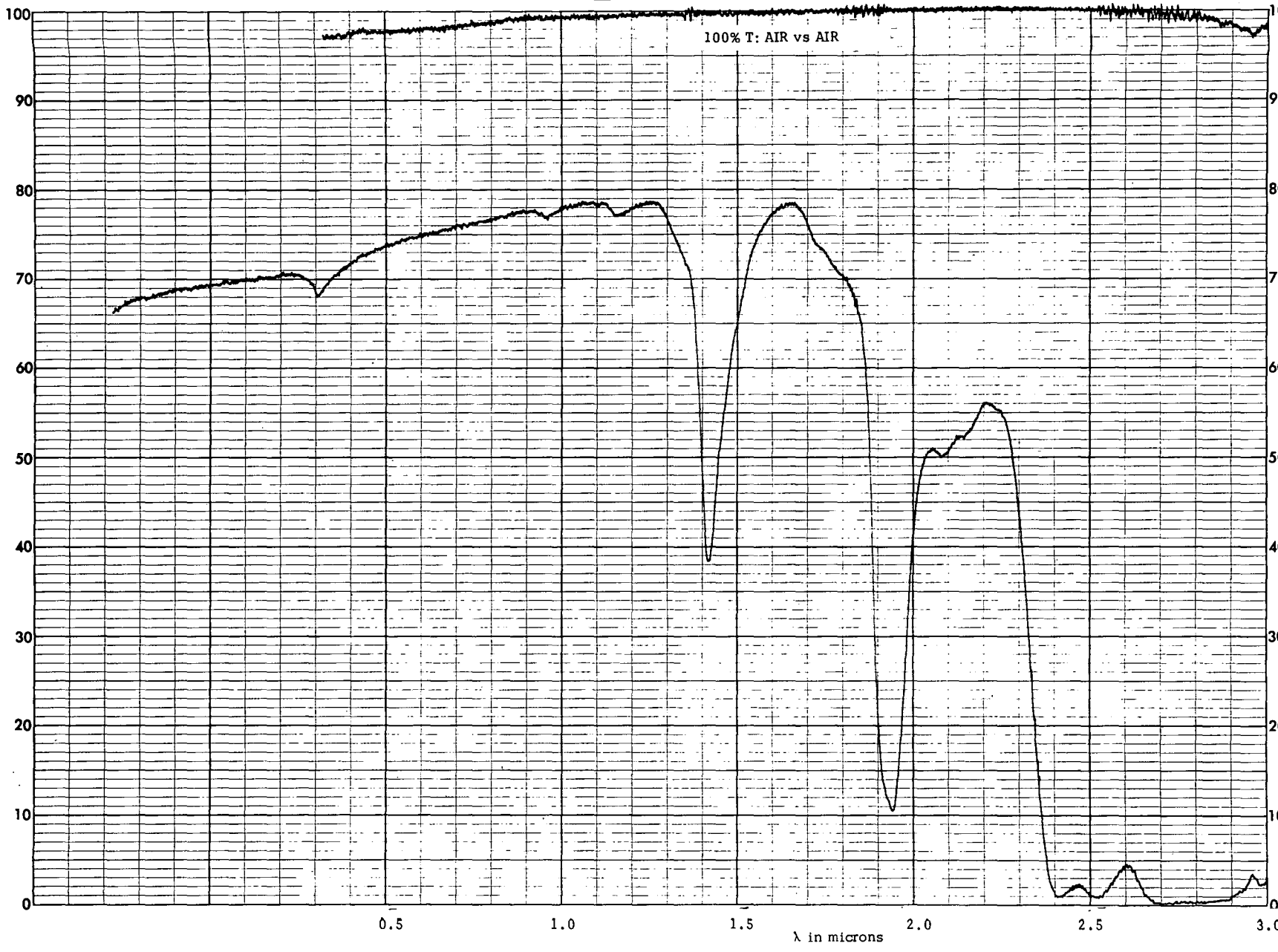
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE $Li_2SO_4 \cdot H_2O$

PATH 0.1 cm

ORIGIN

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W x

H_2

D_2

DETECTOR: PM

PbS x

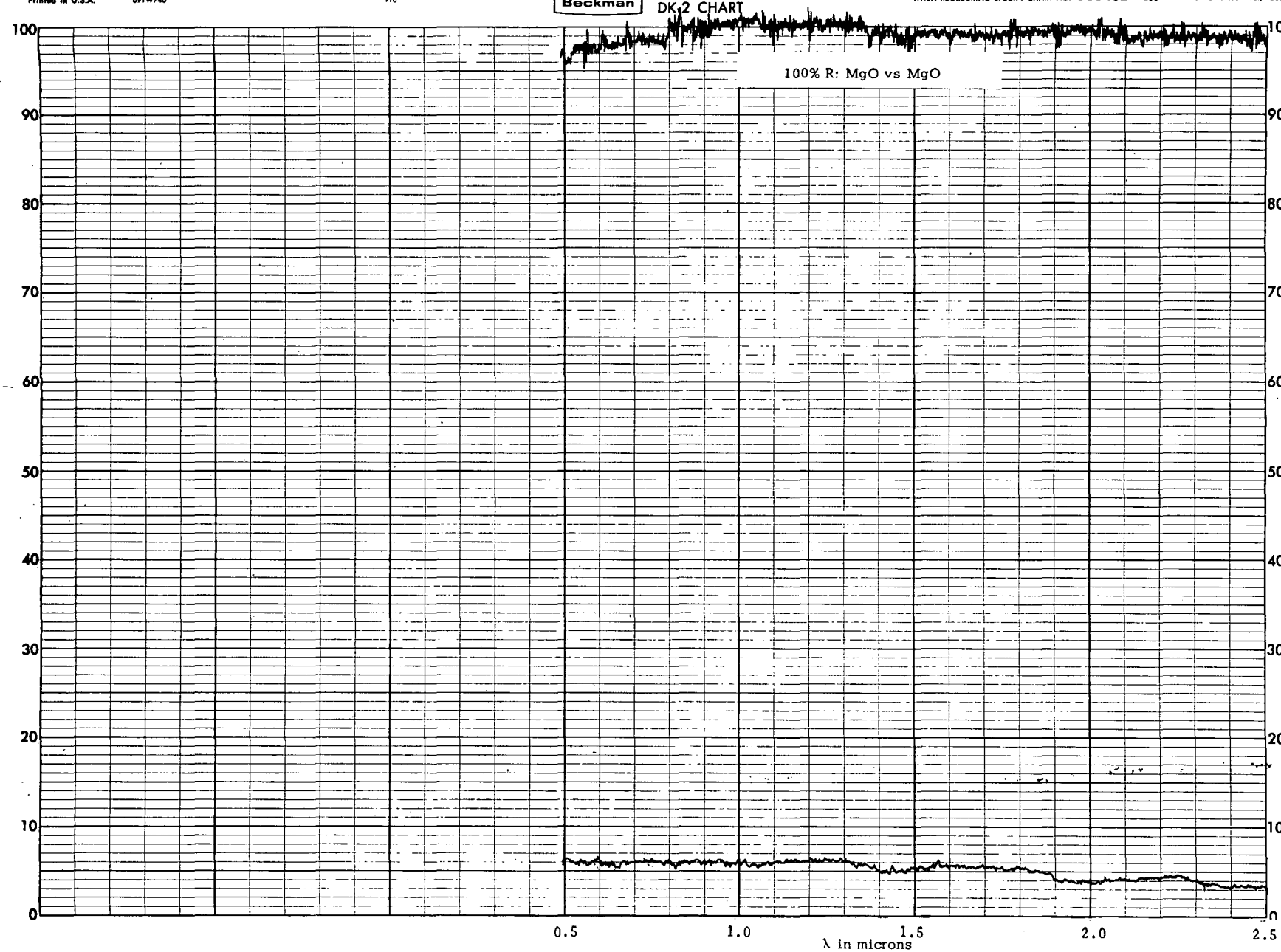
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE

$Li_2SO_4 \cdot H_2O$

PATH cm

ORIGIN

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.2 SEC

SOURCE: W x

H_2

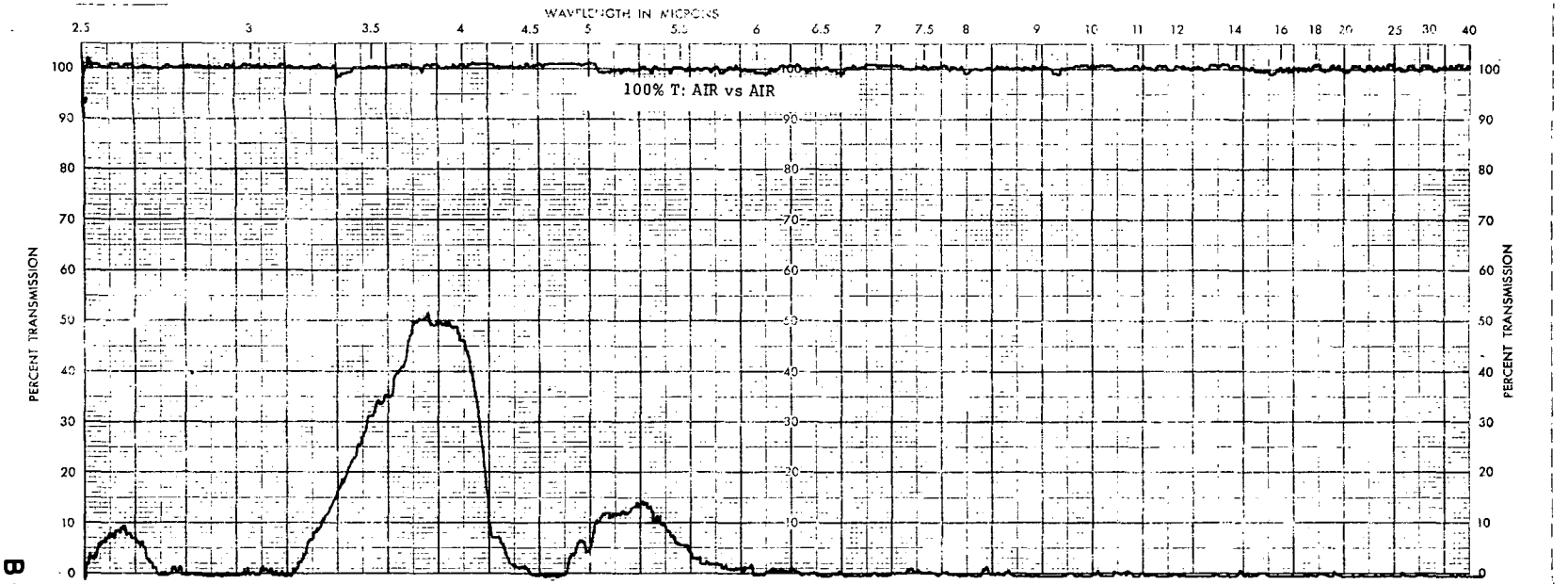
D_2

DETECTOR: PM

PbS x

ANALYST AWB

DATE 11-15-71



SPECTRUM NO.
DATE 11-15-71
SAMPLE $Li_2SO_4 \cdot H_2O$

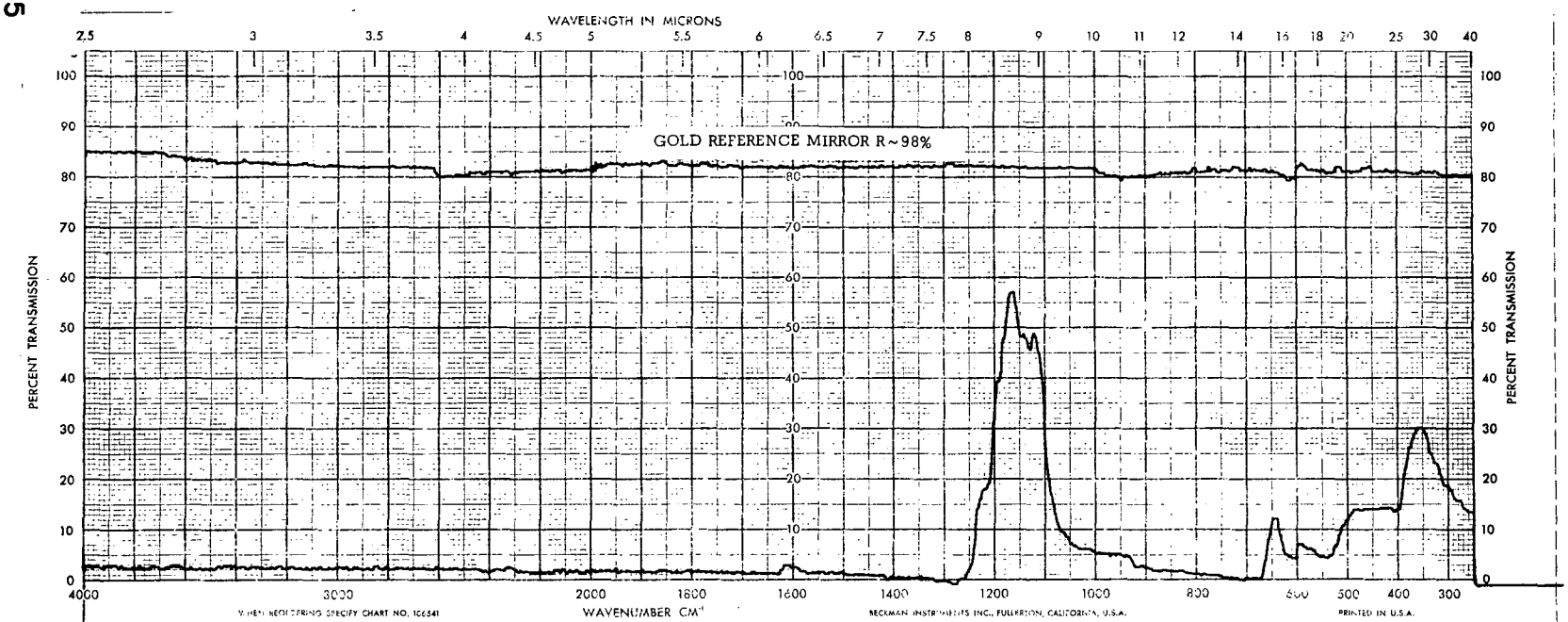
SOURCE BEC
STRUCTURE

IR-20 TRANSMISSION AT NORMAL INCIDENCE

PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST AWB

Beckman®



SPECTRUM NO. 11-15-71
DATE $Li_2SO_4 \cdot H_2O$
SAMPLE

SOURCE BEC
STRUCTURE

IR-20 SPECULAR REFLECTANCE AT 30° INCIDENCE

PATH 1 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS

ANALYST AWB

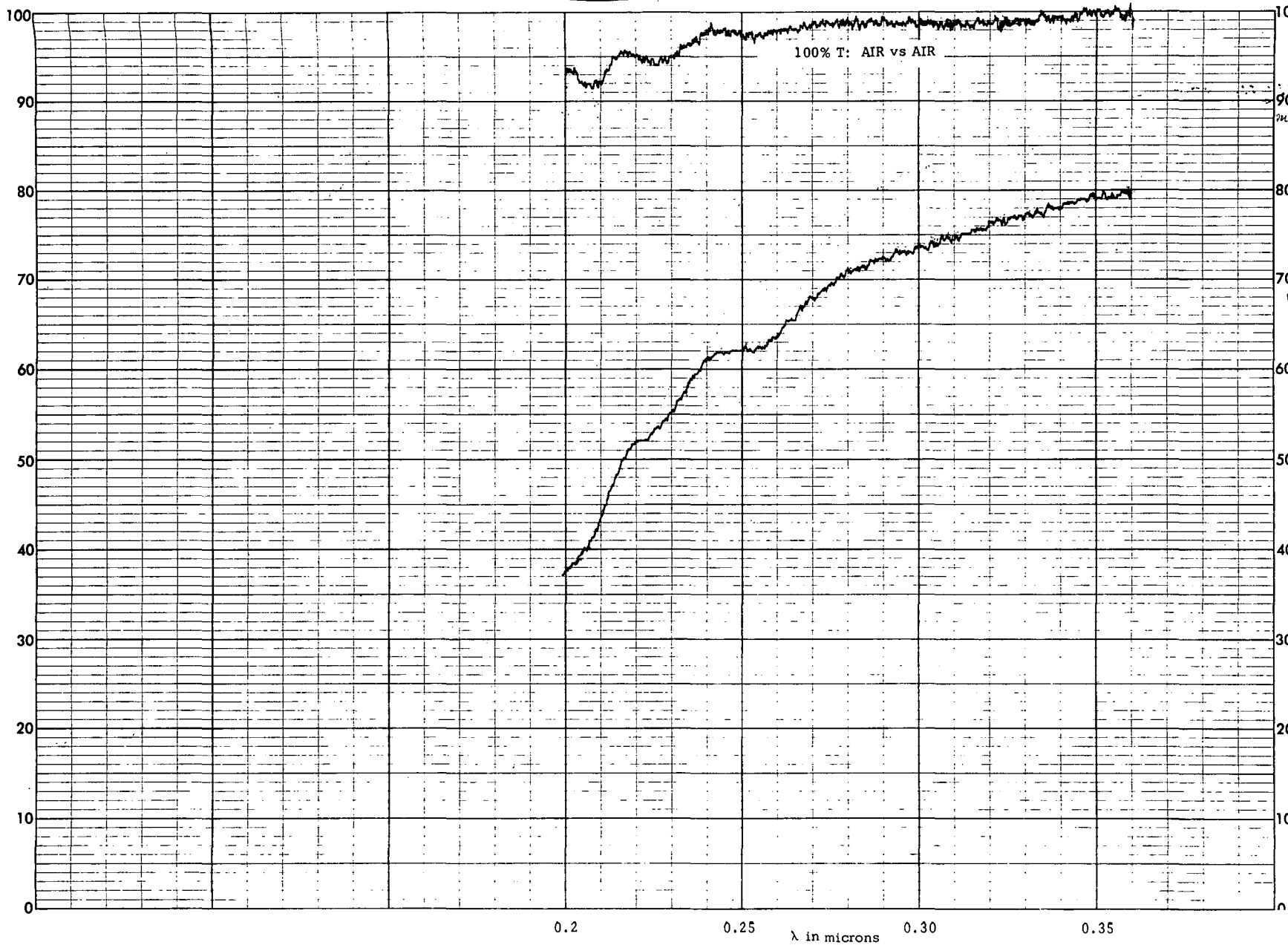
Beckman®

SPECTROPHOTOMETER

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE Polyvinylidene Fluoride

PATH 0.002 cm

ORIGIN BEC

SOLVENT

DK-2 TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.6 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

ANALYST AWB

DATE 11-15-71

B-26

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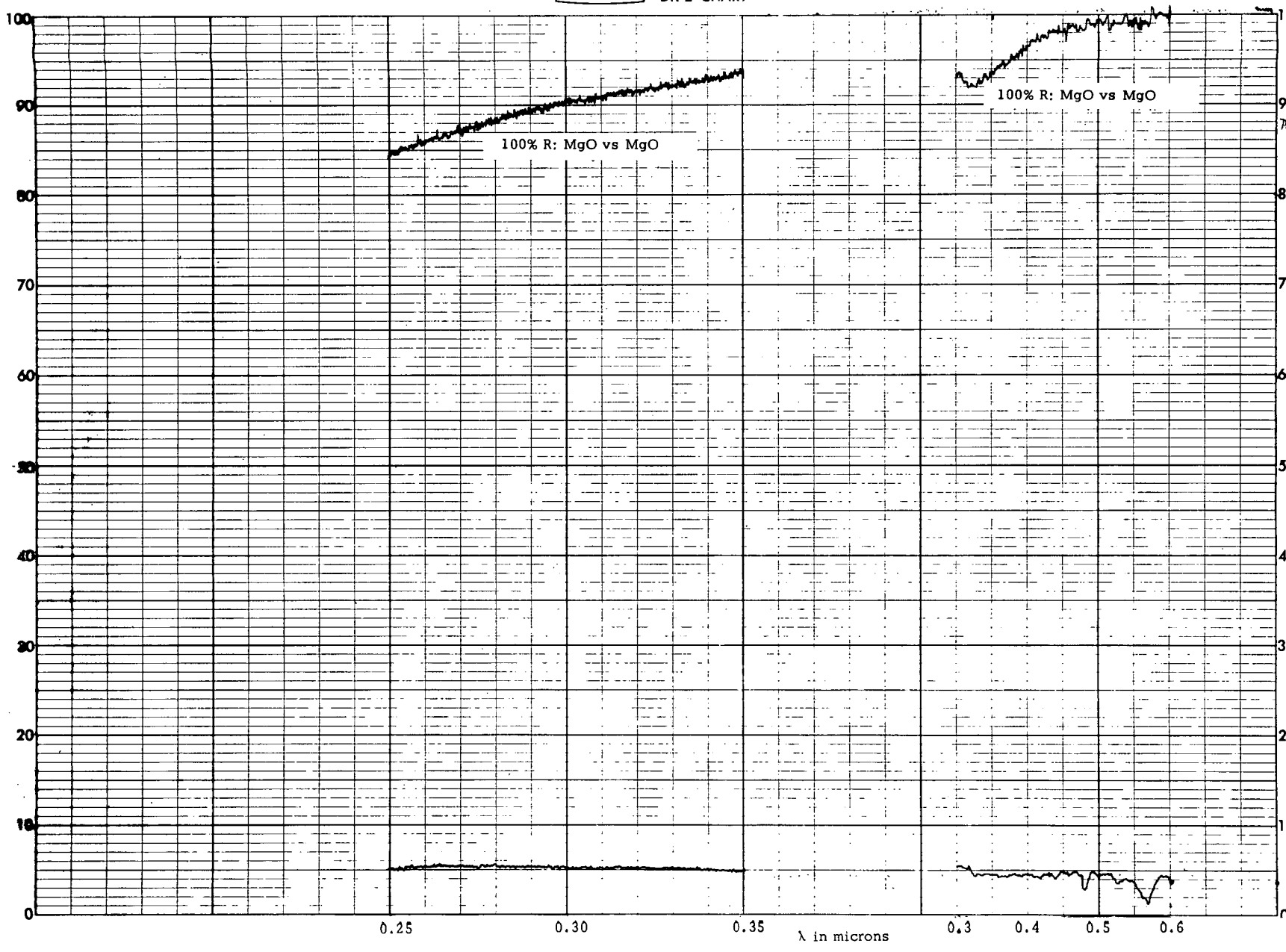
Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE Polyvinylidene Fluoride

PATH 0.1 cm

ORIGIN BEC

SOLVENT

DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.2 SEC

SOURCE: W

H_2

D_2 x

DETECTOR: PM x

PbS

ANALYST AWB

DATE 11-15-71

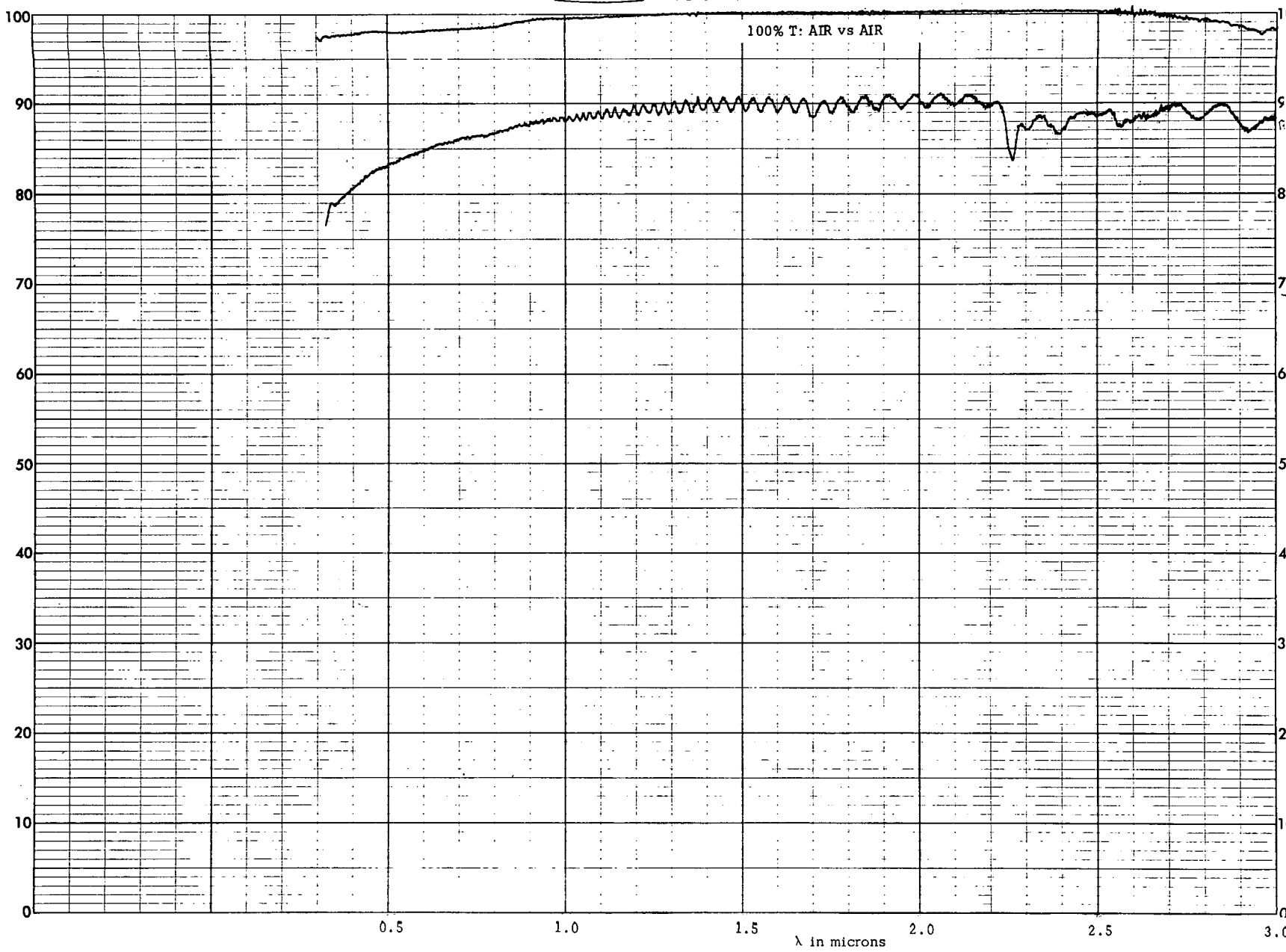
Beckman Instruments, Inc.

B-27

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE Polyvinylidene Fluoride

PATH 0.Φ07 cm

ORIGIN BEC

SOLVENT

TRANSMISSION AT NORMAL INCIDENCE

REF AIR

λ SPEED: 5 nm/min

SCALE 0-100% T

SENS 100

PERIOD 0.2 SEC

SOURCE: W x

H_2

D_2

DETECTOR: PM

PbS x

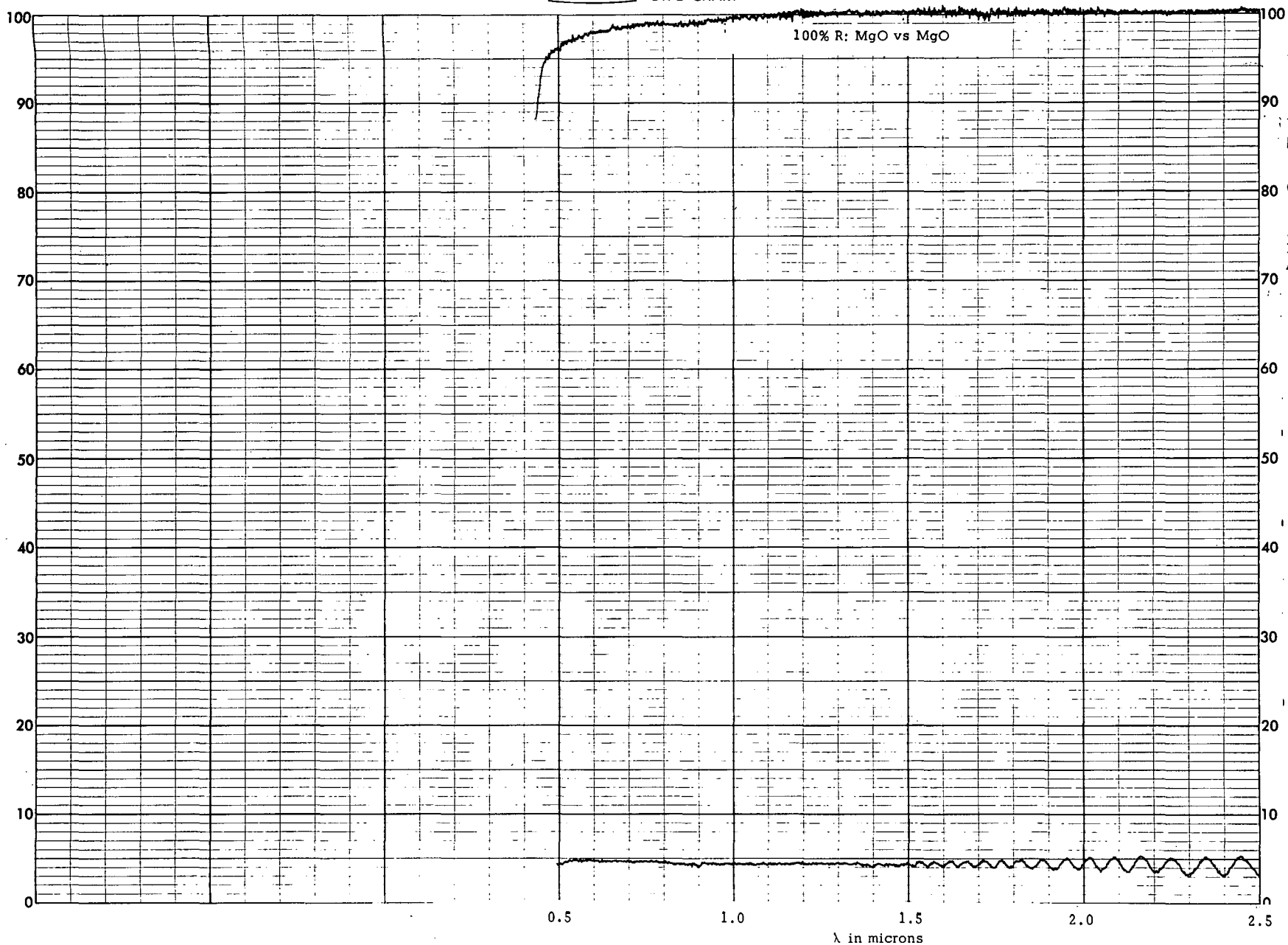
ANALYST AWB

DATE 11-15-71

Printed in U.S.A. 69TW740 910

Beckman DK-2 CHART

WHEN REORDERING SPECIFY CHART NO. 566402 BECKMAN INSTRUMENTS INC., FULLERTON, CALIF., U.S.A.



SAMPLE Polyvinylidene Fluoride

PATH 0.1 cm

ORIGIN BEC

SOLVENT DK-2 REFLECTANCE AT 5° INCIDENCE

REF MgO

λ SPEED: 5 nm/min

SCALE 0-100% R

SENS 150

PERIOD 0.2 SEC

SOURCE: W x

H_2

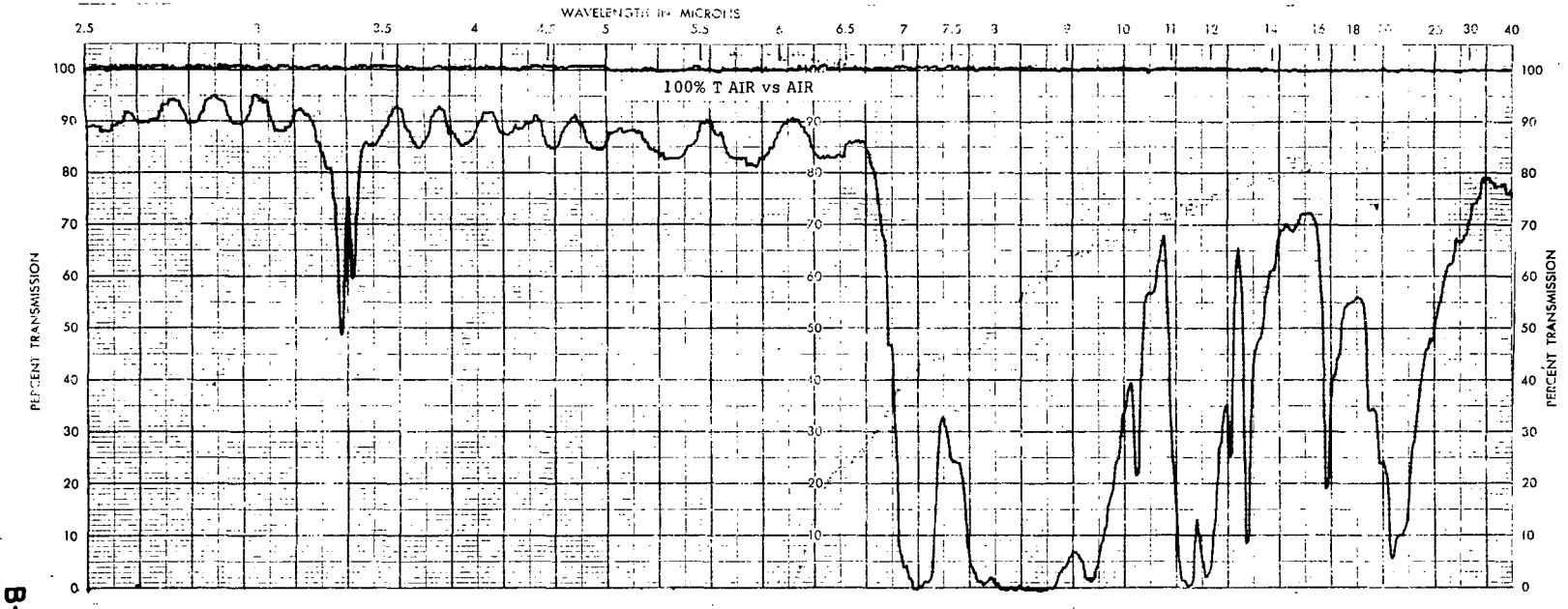
D_2

DETECTOR: PM

PbS x

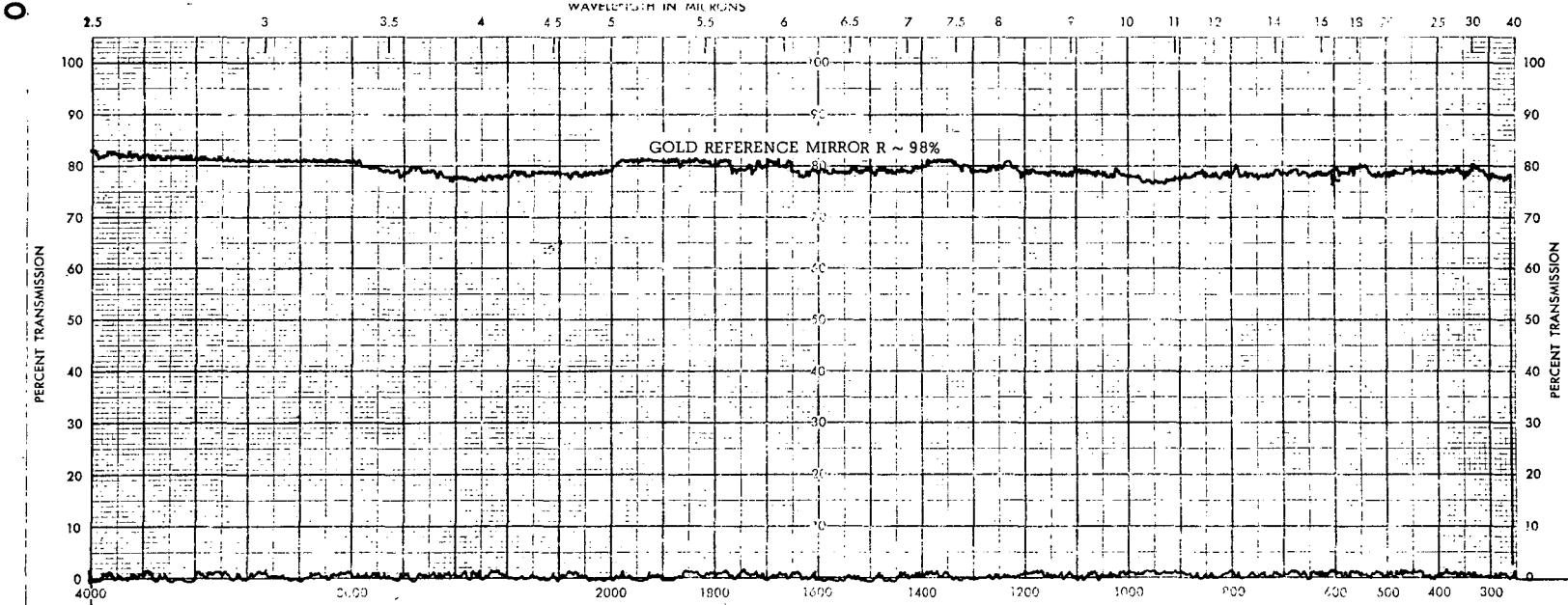
ANALYST AWB

DATE 11-15-71



SPECTRUM NO.
DATE 11-15-71
SAMPLE Polyvinylidene fluoride
SOURCE Korea (Japan)
STRUCTURE
IR-20 TRANSMISSION AT NORMAL INCIDENCE
PATH 0.07 mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS
ANALYST AWB

Beckman



SPECTRUM NO. 11-15-71
DATE
SAMPLE Polyvinylidene fluoride
SOURCE BEC
STRUCTURE
IR-20 SPECULAR REFLECTANCE AT 30° INCIDENCE
PATH mm
SOLVENT
CONCENTRATION
PHASE
COMMENTS
ANALYST AWB

Beckman

SPECTROPHOTOMETER

REFERENCES

(A 1) ANISTRATOV, A.T., Trans. 6th Int, Conf. Ferroelectricity, Riga, 1014 (May 1968).

(A 2) ACKERMANN, W., Ann. Physik, 46, 197 (1915)

(A 3) AZOULAY, J., GRINBERG, Y., PELAH, I., WIENER, E., J. Phys. Chem. Solids, 29, 843 (1968).

(B 1) BEERMAN, H.P., Ferroelectrics, 2, 123 (1971).

(B 2) BERGMAN, J.G., McFEE, J.H., CRANE, G.R., Appl. Phys. Letters, 18, 203 (1971)

(B 3) BŘEZINA, B., STMUTNÝ, B., Czech. J. Phys., B 18, 393 (1968).

(B 4) BEERMAN, H.P., Measurement of ϵ and ρ at Barnes Engr. Co.

(B 5) BRICE, J.C., HILL, O.F., WHIFFIN, P.A.C., WILKINSON, J.A., J. Crystal Growth, 10, 133 (1971).

(B 6) BŘEZINA, B., ŠAFRÁNKOVÁ, M., KVAPIL, J., Phys. Stat. Sol., 15, 451 (1966).

(B 7) BUSCH, G., Helv. Phys. Acta, 11, 269 (1938).

(C 1) Clevite Corp Data (1965).

(C 2) CUMMINS, S.E., Ferroelectrics, 1, 11 (1970).

(C 3) CHYNOWETH, A.G., J. Appl. Phys., 27, 78 (1956).

(C 4) CRANE, G.R., BERGMAN, J.G., GLASS, A.M., presented 71 st Annual meeting, Am. Ceramic Soc. (May 3-8, 1969).

(C 5) CHYNOWETH, A.G., Phys. Rev., 117, 1235 (1960).

(C 6) CHEN, F.S., GEUSIC, J.E., KURTZ, S.K., SKINNER, J.G., WEMPLE, S.H., J. Appl. Phys., 37, 388 (1966).

(C 7) CHYNOWETH, A.G., Acta Crys., 10, 511 (1957).

(D 1) DIMAROVA, E.N., POPLAVKO, Yu.M., Trans. 6th Int. Conf. Ferroelectricity, Riga, 332 (May 1968).

(D 2) DAVISSON, J.W., Acta Cryst., 9, 9 (1956).

(D 3) DeQUERVAIN, M., Helv. Phys. Acta, 17, 509 (1944).

(F 1) FOUSKOVA, A., J. Phys. Soc. Japan, 27, 1699 (1969).

(F 2) FATUZZO, E., HARBECKE, G., MERZ, W.J., NITSCHE, R., ROETSCH, H., RUPPEL, W., Phys. Rev., 127, 2036 (1962).

(G 1) GLASS, A.M., Phys. Rev., 172, 564 (1968).

(G 2) GLASS, A.M., ABRAMS, R.L., J. Appl. Phys., 41, 4455 (1970).

(G 3) GLASS, A.M., J. Appl. Phys., 40, 4699 (1969).

(G 4) GLASS, A.M., Appl. Phys. Letters, 13, 147 (1968).

(G 5) GLASS, A.M., McFEE, J.H., BERGMAN, J.G., J. Appl. Phys.- to be published.

(G 6) GLASS, A.M., Private Communication of Value ρ.

(G 7) GAVRILOVA, N.D., NOVIK, V.K., KOPTSIK, V.A., Sov. Phys.- Cryst., 13, 949 (1969).

(G 8) GULTON INDUSTRIES, INC., (Metuchen, N.J.) - Glennite Piezoceramics data.

(G 9) GOLDSMITH, G.J., WHITE, J.G., J. Chem. Phys., 31, 1175 (1959).

(H 1) HADNI, A., Optics Comm., 1, 251 (1969).

(H 2) HOSHINO, S., MITSUI, T., JONA, F., PEPINSKY, R., Phys, Rev. 107, 1255 (1957).

(H 3) HILCZER, B., Trans. 6th Int. Conf. Ferroelectricity, (Riga 1968), 1023.

(H 4) HOLDEN, A.N., MERZ, W.J., REMEIKA, J.P., MATHIAS, B.T., Phys. Rev., 101, 962 (1956).

(I 1) IWASAKI, H., UCHIDA, N., YAMADA, T., Japan. J. Appl. Phys. 6, 1336 (1967).

(I 2) IWASAKI, H., SUGII, K., YAMADA, T., NIIZEKI, N., Appl. Phys. Letters, 18, 444 (1971).

(I 3) IWASAKI, H., J. Radio Research Lab., Japan, 17, 147 (1970).

(I 4) ITOH, K., MITSUI, T., J. Phys. Soc. Japan, 23, 334 (1967).

(K 1) KUMATA, A., YUMOTO, H., ASHIDA, S., J. Phys. Soc. Japan, 28, 351 (1970 Supplement).

(K 2) KREMENCHUGSKII, L.S., SAMOILOV, V.B., Sov. Phys.-Cryst., 12, 940 (1968).

(K 3) KAMYSHEVA, L.N., et al., Acad. Sci., USSR, Bull. Phys. Ser. 31, 1202 (1967).

(L 1) LANG, S.B., NBS Report #9289, (7-28-1967).

(L 2) LACHAMBRE, J.L., Rev. Sci. Inst., 42, 74 (1971).

(M 1) MATTHIAS, B.T., Science 113, 591 (1951).

(M 2) MÖLLER, K., FARLEIGH DICKINSON U., private communication.

(M 3) MÁLEK, Z., ŠTRAJBLOVÁ, J., NOVOTNÝ, J., MAREČEK, V., Czech. J. Phys. B 18, 1226 (1968).

(M 4) MILEK, J.T., WELLES, S.J., Linear Electrooptics Modulator Materials., Air Force Materials Lab, Air Force Systems Command Contract F33615-68C-1225 to Hughes Aircraft Co., S-14, 143 (Jan. 1970).

(N 1) NASSAU, K., LEVINSTEIN, H.J., LOIACONO, G.M., J. Phys. Chem. Solids, 27, 989 (1966).

(N 2) NAKAMURA, K., WADA, Y., J. Polymer Sc; part A-2, 9, 161 (1971).

(N 3) NOVIK, V.K., Sov. Phys.-Cryst., 10, 89 (1965).

(P 1) PUTLEY, E.H., Proc. Symp. Submillimeter Waves, (N.Y. 1970), 267.

(P 2) PUTLEY, E.H., "Pyroelectric Detectors and their Application in Thermal Imaging Systems", R.R.E. Malvern, Worcs, U.K. - to be published.

(P 3) PEPINSKY, R., VEDAM, K., HOSHINO, S., OKAYA, Y., Phys. Rev. 111, 430 (1958).

(R 1) RABINOVICH, A.Z., ROITBERG, M.B., Sov. Phys.-Cryst., 15, 1023 (May-June 1971).

(S 1) SAVAGE,A., J. Appl. Phys., 37, 3071 (1966).

(S 2) SAWADA, S., NOMURA, S., FUGII, S., YOSHIDA, I., Phys. Rev. Letters, 1, 320 (1958).

(S 3) SANDERS ASSOC.-private communications.

(S 4) STRUKOV, B.A., Proc. Int. Meeting Ferroelectricity, Prague, 1, 191 (1966).

(S 5) SILVESTROVA, I.M., Sov. Phys.-Cryst., 6, 466 (1962).

(S 6) STRUKOV, B.A., Sov. Phys.-Sol. State, 6, 2278 (1965).

(S 7) STRUKOV, B.A., TARASKIN, S.A., KOPTSIK, V.A., VARIKASH, V.M., Sov. Phys.-Cryst., 13, 447 (1968).

(S 8) STRUKOV, B.A.,TARASKIN, S.A., VARIKASH, V.M., Sov. Phys.-Solid State, 10, 1445 (1968).

(S 9) SIL'VESTROVA, I.M., ROMANYUK, N.A., Sov. Phys.-Cryst., 5, 138 (1960).

(S 10) STEPHENSON, C.C., HOOLEY, J.G., J. Am. Chem. Soc., 66, 1397 (1944).

(T 1) TRIEBWASSER, S., Phys. Rev., 114, 63 (1959).

(U 1) ULLMAN, F.G., GANGULY, B.N., ZEIDLER, J.R., Conf. Electronics Materials Comm. of AIME, S. Francisco (August 29-Sept 1, 1971). To be published J. Electronics Mat.

(U 2) ULLMAN, F.G., GANGULY, B.N., HARDY, J.R., Ferroelectrics, 2, (1971) in press.

(U 3) UEDA, S., TATSUZAKI, I., SHINDO, Y., Phys. Rev. Letters, 18, 453 (1967).

(W 1) WIEDER, H.H., PARKERSON, C.R., J. Phys. Chem. Solids, 27, 247 (1966).

(W 2) WILLARDSON, R.K., BEER, A.C., Ed., Semiconductors and Semimetals, 5, Academic Press, (N.Y. & London 1970), 260.

(W 3) WIEDER, H.H., J. Appl. Phys., 30, 1010 (1959).

(W 4) WIEDER, H.H., CLAWSON, A.R., PARKERSON, C.R., J. Appl. Phys., 33, 1720 (1962).

(W 5) WIEDER, H.H., CLAWSON, A.R., PARKERSON, C.R., U.S. Patent #3,337,293.

(W 6) WIEDER, H.H., PARKERSON, C.R., J. Phys. Chem. Solids, 25, 241 (1964).

(Y 1) YAMADA, T., NIIZEKI, N., TOYODA, H., Japan, J. Appl. Phys., 7, 298 (1968).

(Y 2) YURIN, V.A., SILVESTROVA, I.M., ZHELUDEV, I.S., Sov. Phys.-Cryst., 7, 312 (1962)

(Y 3) YURIN, V.A., ZHELUDEV, I.S., Bull. Aca. Science USSR, 28, 633 (1964).

(Z 1) ZHELUDEV, I.S., Zh. Ludupov Ts., Ak. Nauk SSSR, Bull. Phys. Ser. 31, 1207 (1967).

BIBLIOGRAPHY

Milek, J. T. and Welles, S. J., Linear Electrooptic Modulator Materials, EPIC, Hughes Aircraft Co., Culver City, Cal., S-14, Jan. 1970.

Pyroelectric Materials, A Report Bibliography, Search Control Number 047865, Defense Documentation Center, Alexandria, Virginia, 22314.

Connolly, T. F. and Turner E., Compilers, Ferroelectric Materials and Ferroelectricity, Solid State Physics Literature Guides, Vol. 1, IFI Plenum Data Corporation, New York, 1970.

Transactions of the Sixth All-Union Conference on Ferroelectricity, Riga, 15-18 May 1968. Bulletin of the Academy of Sciences of the USSR, Physical Series, Vol. 33, No. 7, pp. 1007-1130, Columbia Technical Translations, New York 1969.

Lang, S. B., Pyroelectricity Bibliography, McGill University, to be published.

Harker, David, Editor, Soviet Physics-Crystallography, Vols. 1 thru 15, English translation of Kristallografiya, American Institute of Physics, N. Y., N. Y. 10017, 1957.

Dvorak, V., Editor, Proceedings of the International Meeting on Ferroelectricity, Vols. 1 & 2, held in Prague, Czechoslovakia, 1966.

Jona, F. and Shirane, G., Ferroelectric Crystals, International Series of Monographs on Solid State Physics, v. 1, Pergamon, 1962.

Muser, H. E. and Petersson, J., Editors, Proceedings of the European Meeting on Ferroelectricity, Saarbrucken, March 27-29, 1969, Wissenschaftliche Verlagesellschaft mbH, Stuttgart, 1970.

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